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Proceedings of the I·R·E

SECOND COLOR TELEVISION ISSUE

This symbolic banner suggests the nature of the FCC-approved color-television signal specified by the National Television System Committee. Successive frequency sections of the color video channel respectively carry trichromatic, bichromatic, and monochromatic representations of large areas and progressively finer detail of the picture.

IN THIS ISSUE

- Presentations by NTSC Officials
- NTSC Signal Specifications
- NTSC Technical Monographs
- Colorimetric Studies
- Color Television System Performance
- Color Television Circuitry and Equipment

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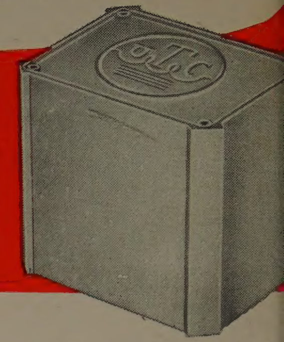
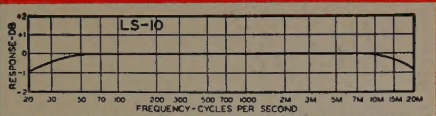
The Institute of Radio Engineers

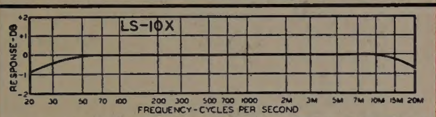
FOR Higher Fidelity*

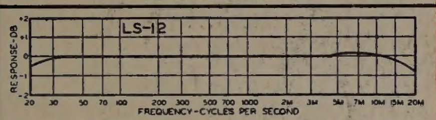
THE Linear Standard SERIES

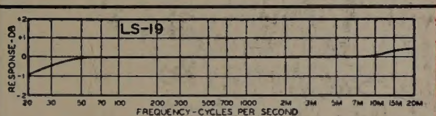


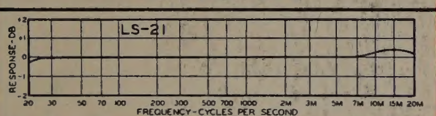
The ever increasing use of wide range equipment for broadcast service has reached the point where the major limiting factor is the frequency range of the transformers employed. UTC Linear Standard components represent the closest approach to the ideal transformer from the standpoint of uniform frequency response, low wave form distortion, high efficiency, thorough shielding, and dependability. Typical LS units are described below.

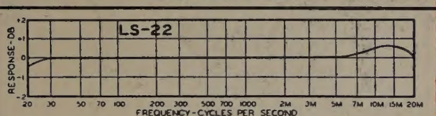


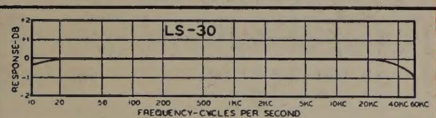


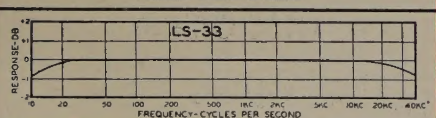


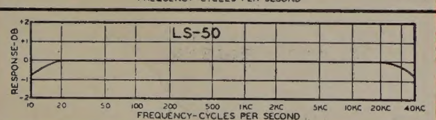


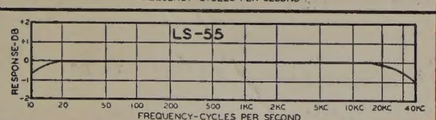


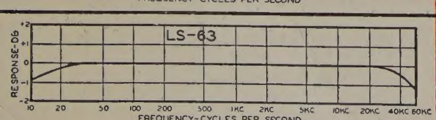


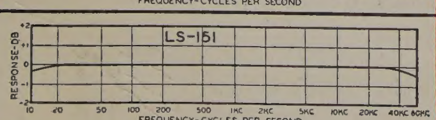












INPUT TRANSFORMERS

Case Size	LS-1	LS-2
Length	3⅛"	4 7/16"
Width	2⅝"	3½"
Height	3¼"	4 3/16"

Type No.	Application	Primary Impedance	Secondary Impedance	± 1 db from	Max.† Level	Relative* hum	Unbal. DC in prim'y	Case No.	List Price
LS-10	Low impedance mike, pickup, or multiple line to grid	50, 125/150, 200, 250, 333, 500/600 ohms	60,000 ohms in two sections	20-20,000	+10 DB	−74 DB	.5 MA	LS-1	$25.00
LS-10X	As above	As above	50,000 ohms	20-20,000	+10 DB	−92 DB-Q	.5 MA	LS-1	35.00
LS-12	Low impedance mike, pickup, or multiple line to push pull grids	50, 125/150, 200, 250, 333, 500/600 ohms	120,000 ohms overall, in two sections	20-20,000	+10 DB	−74 DB	.5 MA	LS-1	28.00
LS-12X	As above	As above	80,000 ohms overall, split	20-20,000	+10 DB	−92 DB-Q	.5 MA	LS-1	35.00
LS-15X	Three isolated lines or pads to one or two grids	30, 50, 200, 250 ohms each primary	60,000 ohms overall, in two sections	20-20,000	+10 DB	−92 DB-Q	.5 MA	LS-1	37.00

INTERSTAGE AND MATCHING TRANSFORMERS

Type No.	Application	Primary Impedance	Secondary Impedance	Response	Max.† Level	Relative* hum	Unbal. DC in prim'y	Case No.	List Price
LS-19	Single plate to push pull grids like 2A3, 6L6, 300A. Split secondary	15,000 ohms	95,000 ohms; 1.25:1 each side	± 1 db 20-20,000	+12 DB	−50 DB	0 MA	LS-1	$26.0
LS-21	Single plate to push pull grids. Split pri. and sec.	15,000 ohms	135,000 ohms; 3:1 overall	± 1 db 20-20,000	+10 DB	−74 DB	0 MA	LS-1	26.0
LS-25	Push pull plates to push pull grids. Medium level. Split primary and sec.	30,000 ohms plate to plate	50,000 ohms; turn ratio 1.3:1 overall	± 1 db 20-20,000	+15 DB	−74 DB	1 MA	LS-1	32.0
LS-30	Mixing, low impedance mike, pickup, or multiple line to multiple line	50, 125/150, 200, 250, 333, 500/600 ohms	50, 125/150, 200, 250, 333, 500/600 ohms	± 1 db 20-20,000	+15 DB	−74 DB	.5 MA	LS-1	26.0
LS-33	High level line matching	1.2, 2.5, 5, 7.5, 10, 15, 20, 30, 50, 125, 200, 250, 333, 500/600	50, 125, 200, 250, 333, 500/600 ohms	± .2 db 20-20,000	15 watts			LS-2	30.0

OUTPUT TRANSFORMERS

Type No.	Application	Primary Impedance	Secondary Impedance	Response	Max.† Level	Relative* hum	Unbal. DC in prim'y	Case No.	List Price
LS-50	Single plate to multiple line	15,000 ohms	50, 125/150, 200, 250, 333, 500/600	± 1 db 20-20,000	+15 DB	−74 DB	0 MA	LS-1	$26.0
LS-52	Push pull 245, 250, 6V6 or 245 A prime	8,000 ohms	500, 333, 250, 200, 125, 50, 30, 20, 15, 10, 7.5, 5, 2.5, 1.2	± .2 db 25-20,000	15 watts			LS-2	35.
LS-55	Push pull 2A3's, 6A5G's, 300A's, 275A's, 6A3's, 6L6's, 6AS7G	5,000 ohms plate to plate and 3,000 ohms plate to plate	500, 333, 250, 200, 125, 50, 30, 20, 15, 10, 7.5, 5, 2.5, 1.2	± .2 db 25-20,000	20 watts			LS-2	35.
LS-63	Push pull 6F6, class B 46's, 6AS7G, 807-TR, 1614-TR	10,000 ohms plate to plate and 6,000 ohms plate to plate	30, 20, 15, 10, 7.5, 5, 2.5, 1.2	± .2 db 25-20,000	15 watts			LS-2	25.
LS-151	Bridging from 50 to 500 ohm line to line	16,000 ohms, bridging	50, 125/150, 200, 250, 333, 500/600	± 1 db 15-30,000	+18 DB	−74 DB	1 MA	LS-1	27.

The values of unbalanced DC shown will effect approximately 1.5 DB loss at 30 cycles.
* Comparison of hum balanced unit with shielding to normal uncased type. Q Multiple alloy magnetic shield.
† 6 MW as ODB reference.

* UTC LINEAR STANDARD transformers are the ONLY audio units with a GUARANTEED uniform response ... 1 DB from 20 to 20,000 cycles.

United Transformer Co.

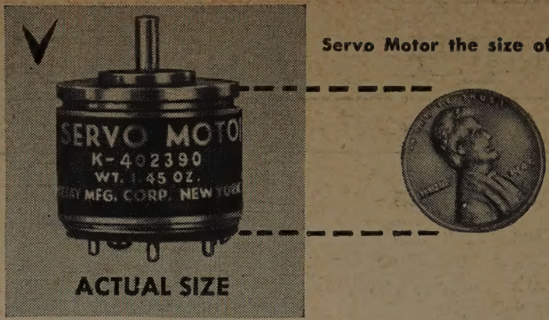
150 VARICK STREET • NEW YORK 13, N. Y.

EXPORT DIVISION: 13 EAST 40th STREET, NEW YORK 16, N. Y. CABLES: "ARLAB"

TYPICAL CHARACTERISTICS

MECHANICAL DATA		ELECTRICAL DATA	
Weight	1.45 oz.	No load speed	6,500 RPM
Rotor inertia	.46 gm-cm²	Stall torque	.3 oz.-in.
Theoretical acceleration	49,000 RAD/SEC²	Maximum output	.490 W.
		Single phasing	None

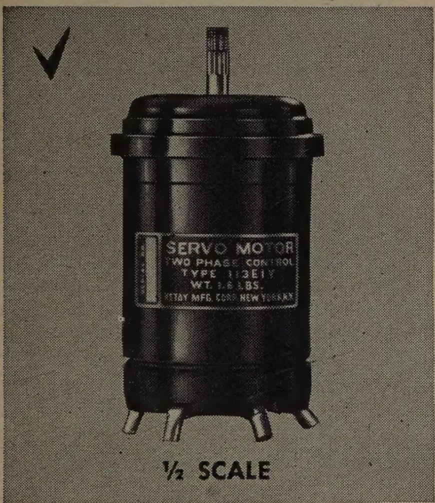
DATA AT STALL	FIXED PHASE	CONTROL PHASE
Voltage (volts)	26	26
Frequency (cycles)	400	400
Current (ma.)	166	166
Power imput (watts)	3.1	3.1
Power factor	.63	.63
R—ohms	98.5	98.5
X—ohms	123	123
Z—ohms	157	157



Servo Motor the size of a Penny

Ketay's Experience helps you

Servo Motor in a size 23 Frame, 6 watt



TYPICAL CHARACTERISTICS

MECHANICAL DATA		ELECTRICAL DATA	
Weight	1.6 lbs.	No load speed	3,500 RPM
Rotor inertia	20.0 gm-cm²	Stall torque	7.5 oz.-in.
Theoretical acceleration	26,500 RAD/SEC²	Maximum output	6.0 W.
		Single phasing	None

DATA AT STALL	FIXED PHASE	CONTROL PHASE Series	CONTROL PHASE Parallel
Voltage (volts)	115	115	57.5
Frequency (cycles)	60	60	60
Current (ma.)	175	175	350
Power imput (watts)	14.0	14.0	14.0
Power factor	0.70	0.70	0.70
R—ohms	460	460	115
X—ohms	470	470	117
Z—ohms	660	660	164

Also for 115V or 230V operation on control phase.

Check these Servo Motors against your needs

Ketay offers a complete line of high precision **SYNCHROS, SERVO MOTORS and RESOLVERS.**

Ketay's experience also includes: automatic control devices for use in fire control and missile systems; computers and simulators; amplifiers; marine inter-communication equipment; remote indicators such as ship course indicators, drive angle indicators and salinity indicators; and automatic control systems.

Mail coupon today for bulletin containing specifications on 100 types of Synchros, Servo Motors and Resolvers.

Servo Motor in a size 15 Frame, 60 cycle, 115 volt

TYPICAL CHARACTERISTICS

MECHANICAL DATA		ELECTRICAL DATA	
Weight	7.3 oz.	No load speed	3,300 RPM
Rotor inertia	3.03 gm-cm²	Stall torque	1.45 oz.-in.
Theoretical acceleration	33,800 RAD/SEC²	Maximum output	1.23 W.
		Single phasing	None

DATA AT STALL	FIXED PHASE	CONTROL PHASE Series	CONTROL PHASE Parallel
Voltage (volts)	115	115	57.5
Frequency (cycles)	60	60	60
Current (ma.)	53	53	106
Power imput (watts)	5.0	5.0	5.0
Power factor	.82	.82	.82
R—ohms	1780	1780	445
X—ohms	1240	1240	310
Z—ohms	2170	2170	542

Ketay

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New York Division • Kinetix Instrument Division • Pacific Division
Electronic Instrument Division • Research & Development Division

Ketay Manufacturing Corp. A
555 Broadway, New York 12, N. Y.

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COMPANY....................
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CITY.................... STATE....................
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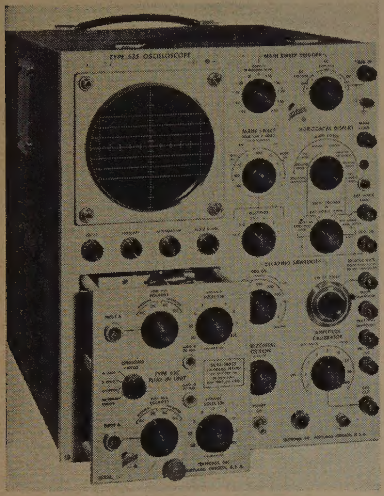
Oscilloscopes

Tektronix, Inc., P.O. Box 831, Portland 7, Ore., has a new Type 535 C-R oscilloscope, with plug-in preamplifiers and a new sweep delay circuit.



Twenty-four calibrated sweeps are provided by the new sweep circuit, ranging from 0.1 μsec/cm to 5 sec/cm with 5× magnification on all ranges, and continuously variable uncalibrated sweeps from 0.1 μsec/cm to 10 sec/cm. Automatic main sweep lockout with controllable reset permits accurate delay of the start of the main sweep from 10 μsec to 20,000 μsec. Trigger selector permits automatic triggering or amplitude selection. Balanced delay network provides 0.25 μsec signal delay. Price of the basic unit is $1385.00.

Three different plug-in preamplifiers are available for use with the oscilloscope.

Called the Dual-Trace Unit, Model 53C has two identical amplifier channels, activated on alternate sweeps, or nonsynchronously at approximately 100 kc. Both amplifier channels have a 0.04 μsec rise time, dc to 8.5 mc bandpass, and 0.05 v/cm to 20 v/cm sensitivity in nine calibrated steps. Sensitivity is continuously variable between steps and extends to 50 v/cm. Four-position ac-dc and polarity reversal switches are provided. Price is $275.00.

Type 53D Differential High-Gain DC Unit has a sensitivity of 1 mv/cm to 50 v/cm in 24 calibrated steps, with variable sensitivity between steps. Bandpass is dc to 250 kc at maximum sensitivity, extending to 750 kc at 50 mv and lower. A six-position ac-dc input selector switch is provided. Price is $145.00.

Type 53A Wide-Band DC Unit has a 0.035 μsec rise time, dc to 10 mc bandpass, and 0.05 v/cm to 20 v/cm sensitivity in nine calibrated steps. Sensitivity is continuously variable between steps and extends to 50 v/cm. Two signal inputs with 60 db isolation are provided, with a four-position ac-dc and input selector switch. Price is $85.00.

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

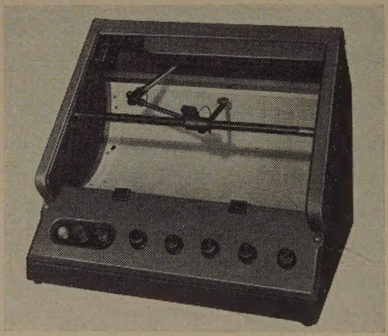
Accelerometer Bulletin

Gulton Mfg. Corp., Metuchen, N. J., recently published a catalog sheet describing their Glennite Accelerometers.

Bulletin A314 lists Models A314, A315, A316, and A317, giving their nominal and individual characteristics. A frequency response graph and a typical response trace are shown. Linearity and temperature stability are mentioned.

Plot-Trace Recorder

Librascope, Inc., 1607 Flower St., Glendale, Calif., announces the X-Y Plotter and Recorder, a new two-coordinate portable recording instrument for continuous curve or discrete point plotting. The instrument is useful for the display of digital information, the plotting of transistor characteristics, or for calibration of such equipment as flow meters, and so forth.



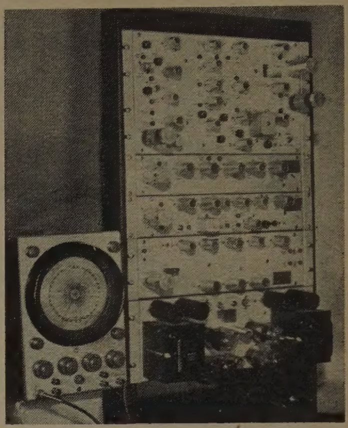
The X-Y Plotter and Recorder is designed either for desk use or for rack-mounting, in the latter case fitting the standard RCA or RMA racks. The desk unit shown is 16 high, 19 wide and 16½ inches deep. The unit is entirely self-contained.

The plotting surface is a stationary concave 120° cylinder and takes either 11×16½ inch or 8½×11 inch standard graph paper held down by magnetic clips. Ink supply is accessible and is pressure regulated.

Controls are located on the front panel and consists of dials registering OFF, STANDBY, and 4-QUAD. 4-Quad operation accepts either negative or positive values on either axis. Origin may be shifted to any part of the chart. Zero offset and scale expansion of either axis is continuously variable over 10 to 1 range. The pen can be directed to plot or trace by single switch control. The X-Y Recorder is accurate to ±0.1 per cent full scale (static) and operates on 150 watts, 115 volts, 60 cps. Accessories are available.

Color TV Test Equipment

An instrument for checking the quality of color TV equipment has been designed by **Telechrome, Inc.,** 88 Merrick Rd., Amityville, L. I., N. Y.

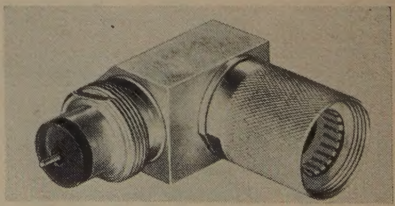


The newest addition to the Telechrome line, Model 1601-AR Chromascope, is designed for receiver manufacturers, TV broadcasters, and research laboratories to measure the performance, alignment, and phase errors of color TV equipment.

All possible colors of a color TV transmission together with color sync information are presented on a cathode-ray screen (a vector chroma presentation) in their precise relation to each other. The Chromascope certification and monitoring equipment checks the phase and amplitude of each color present.

Right Angle Pulse Type Connector

A new Pulse Type Connector (Model B2897) has been developed recently by **H. H. Buggie, Inc.,** 726 Stanton St., Toledo 4, Ohio. It mates with standard UG 182 A/U receptacle, and a male panel mounted receptacle of the same series. The size is approximately 2 27/32 inches by 3 ¼ inches.



The part is designed for service at high voltage, 5,000 volts peak at 50,000 altitude. It is produced to surpass military specifications.

The shell is made from brass, and has a tin plate finish. Complete details will be mailed to engineers and buyers, directing their requests to the company.

(Continued on page 14A)

News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 10A)

Miniature Hermetic Audio Transformer

Designed for small lightweight electronic aircraft and mobile equipment, a new hermetically sealed transformer is being manufactured by **Thermador Electrical Mfg. Co.,** Electronic Div., 2000 Camfield Road, Los Angeles, Calif.

The Thermador "HO" Hermetic-Ouncers are 15/16 inch in diameter and 1⅜ inches high, and weigh from 1 to 1¾ ounces. They feature 40 db magnetic shielding; 200°F operating temperature; true hermetic sealing. Delivery is immediate from stock.

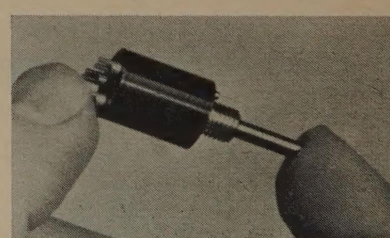
For further information write to the firm.

Printed Circuit Brochure

Centronics Co., 21-04 122 St., College Point, L.I., N.Y., has published a 4-page brochure on their printed circuit techniques, applications, and design service, which is available to the industry. Various types of materials are mentioned, giving data as to water absorption, dielectric constant, and dissipation factor.

Miniature Wire-Wound Potentiometers

Aerohm Corp., 282 Moody St., Waltham 54, Mass., is producing a new linear, wire-wound potentiometer, the AP-½, designed to solve requirements for small space and light weight. Its all-metal case is ½ inch in diameter ×⅝ inch deep. The standard model weighs less than ½ ounce. Because of the AP-½'s full sealed construction, it may be used where military requirements for resistance to humidity, salt spray, shock, vibration, and fungus must be met.



This potentiometer will operate between −55°C and +85°C. At 29°C, its dissipation is approximately 5 watts. In addition to these characteristics, the AP-½ has soldered electrical connections, precious metal contacts to windings and slip rings, coin silver tabs to protect end turns, and gold-plated forked terminals to facilitate wiring.

Resistance range, from 10 to 10,000 ohms. Shaft locks, rotational stops, special shafts and bushings are available on order.

(Continued on page 24A)

News—New Products

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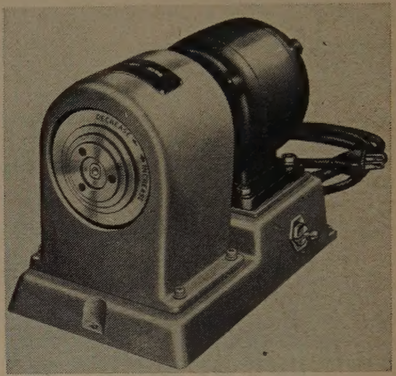
(Continued from page 14A)

Rotary Wire Stripper

Rush Wire Stripper Div., The Eraser Co., 1090 S. Clinton St., Syracuse 4, N. Y., has a new Model "G-5" Wire Stripper, a rotary stripper using a single blade which can be adjusted to within 0.001 inch. This stripper is designed to strip any insulation which can be cut through and then pulled off by withdrawing wire from stripper. It is limited to wires having a diameter not greater than 0.255 inch over the insulation.



The manufacturer states the Model "G-5" Wire Stripper will positively not nick or damage the bare wire as may happen when more than a single cutting blade is used. Stranded wires are twisted in stripping operation.

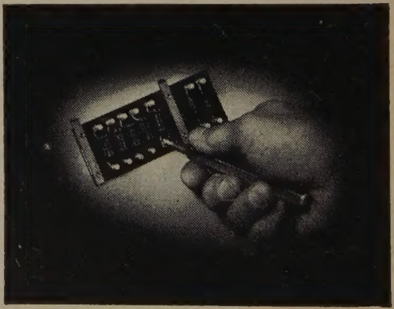
Precision guide bushings are provided to fit all wires to be stripped.

Machine is 6½ wide, 10½ deep, 7½ inches high and comes mounted on a bench-height stand with foot treadle and plastic bag to catch slugs of insulation. Machine may also be mounted on bench.

Stripping Head is mounted directly on shaft of 1/20 HP, 1725 rpm motor, with reversing switch. Contact firm for details.

Terminal Tool for Wire Wrapping

Contact, Inc., 238 Main St., Cambridge 42, Mass., announces production of the "Wire-Wrench," a tool for wrapping either stranded or solid wire around terminals on boards, or hermetic seals.



One or more wires can be wrapped around a terminal with a single twist of the wrist. The wire is placed against the

(Continued on page 25A)

News—New Products

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(Continued from page 24A)

terminal; the tool is placed over the terminal so that the wire is caught in the notch of the tool; a twisting motion is applied which wraps the wire around the terminal in a neat, tight connection, ready for soldering.

"Wire-Wrench" also has an auxiliary feature, a drilled hole and a milled flat to be used for putting a hook in a wire whenever needed. The tool can be used for straightening bent terminals, as well. Three sizes are available: #WW1, for miniature terminals; #WW2, for medium-size terminals; #WW3, for large terminals.

Power Supply

The Kepco Laboratories, Inc., 131–38 Sanford Ave., Flushing, L. I., N. Y., are manufacturing a new Model #2400 Voltage-Regulated Power Supply which features two regulated B supplies completely isolated from each other, one regulated C supply, and two unregulated filament supplies isolated from each other.

Each of the B supplies is continuously variable from 0 to 400 volts and delivers from 0 to 150 ma. In the range 20–400 volts the output voltage variation is less than ½ per cent for both line fluctuation from 105 to 125 volts and load variations from minimum to maximum current. The ripple voltage is less than 5 millivolts. The B supplies may be used separately, in parallel or in series. For parallel operation the output voltage is 0 to 400 volts, the output current is 0 to 300 ma. For the series operation the output voltage is 0 to 800 volts, the output current is 0 to 150 ma.

The C supply is continuously variable from 0 to 150 volts and delivers from 0 to 5 ma. For all output voltages the variation is less than 10 millivolts for line fluctuations from 105–125 volts. At 150 volts the regulation is less than ½ per cent for variation in load from 0 to 5 ma. At settings below 150 volts the internal resistance of the supply will increase to a maximum of 27,500 ohms. The ripple voltage is less than 5 millivolts.

Each filament supply delivers 6.3 volts, 10 amperes, and is unregulated, center tapped and ungrounded. Filament supplies may be used separately, in parallel or in series.

(Continued on page 33A)

News—New Products

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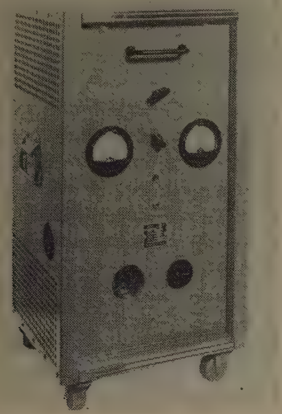
(Continued from page 25A)

12-Volt DC Supply

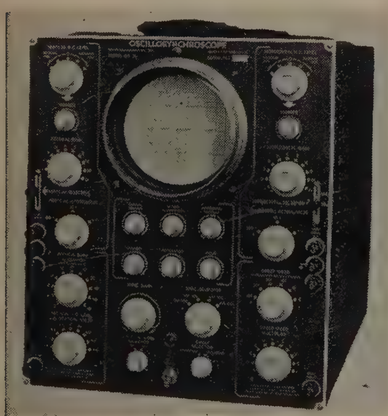
A new, tubeless, regulated dc supply, designed especially for the automotive industry and using magnetic amplifier principles, is now available from **Sorensen & Co., Inc.,** 375 Fairfield Ave., Stamford, Conn. The unit, Nobatron Model MA6/15, is intended for use in checking window motors, heaters, clocks, radios, headlight dimmers, ignition systems, and so forth. The high capacity of the instrument makes it useful in a wide range of applications.



The MA6/15 delivers 100 amperes at 6 volts (adjustable to 7.7 volts) or 75 amperes at 12 volts (adjustable to 15.4 volts). Regulation is ±0.1 per cent against line and load combined. For full information, write to Sorensen.

Oscillosynchroscope

Browning Laboratories, Inc., 750 Main St., Winchester, Mass., announces their Model OA-16 Oscillosynchroscope, featuring a calibrated buck-out voltage which allows balancing out of dc levels accurately



to 10 per cent. This enables small superimposed ac signals to be expanded for more minute inspection of both the signal and small changes in dc level. This represents a possible 40:1 expansion of the signal over that observable using conventional dc methods.

Also featured are vertical and hori-

(Continued on page 50A)

Seven years a SELETRON CUSTOMER!

CABLE ADDRESS RIALRECT N Y

TELEPHONE FLUSHING 3 2828

RICHARDSON-ALLEN CORPORATION
RECTIFIER SPECIALISTS

116-15 FIFTEENTH AVENUE
COLLEGE POINT, LONG ISLAND
NEW YORK

October 19, 1953.

Mr. Julian Loebenstein, Sales Manager
Seletron and Germanium Division,
Radio Receptor Company, Inc.,
251 West 19th Street,
New York 11, N. Y.

Dear Mr. Loebenstein:

We are planning a considerably expanded production for the new year and would like to know whether we can depend upon you for much heavier deliveries of the rectifiers we shall need.

Naturally we guard our reputation as manufacturers of power supplies carefully and, therefore, all components used must rank tops in their class -- with special attention to the rectifier stacks since the performance of our equipment depends so largely on them.

For the past seven years your Seletron selenium rectifiers have done a splendid job for us in applications for low voltage electroplating, and for power supplies of 110/220 volts. Both types of use involve individual jobs running into many kilowatts.

We are very greatly pleased with both your product and service which have helped result in repeated reorders from our customers and, therefore, want to be able to count on you to take care of our growing business.

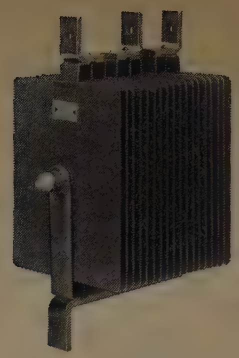
Sincerely yours,

RICHARDSON-ALLEN CORPORATION

Harry Walker

Harry Walker,
Vice President.

HW:lk

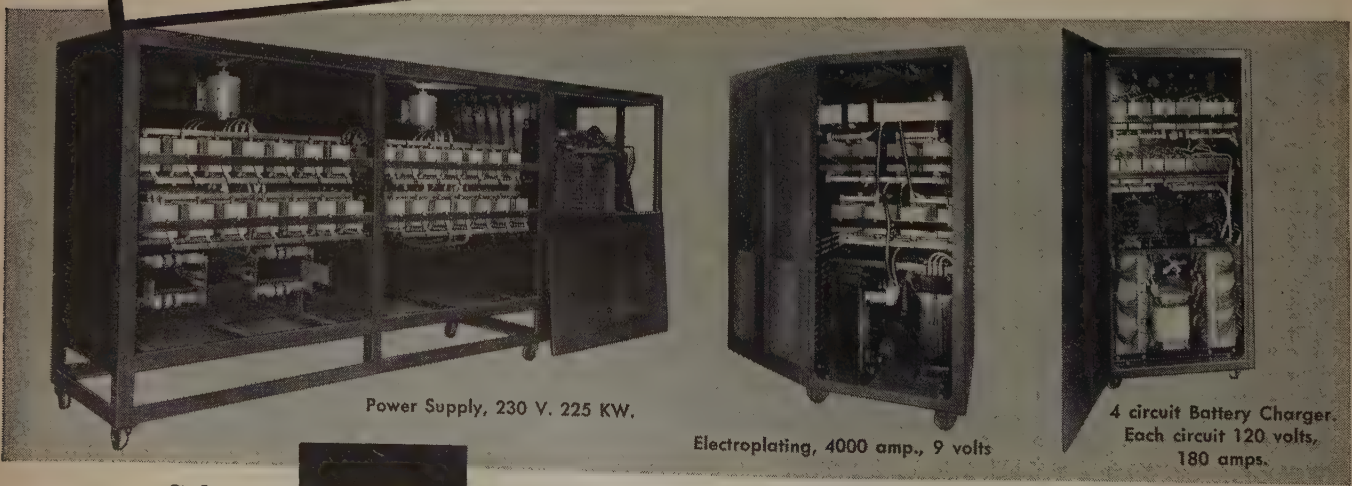


Seletron SELENIUM RECTIFIERS

When the problem is industrial rectification, a great number of rectification specialists such as Richardson-Allen Corporation look to SELETRON to do a lasting, dependable job. Need we amplify? The record speaks for itself.

SELETRON Selenium Rectifiers are available up the line from miniatures for Radio and TV and other electronic circuits, all the way to large power stacks required by heavy industry.

Do *you* need information on a problem in a rectification? We'll gladly help without obligation if you drop us a note today... and study our catalog in Sweet's Product Design File. *We also manufacture germanium diodes and transistors.*



Power Supply, 230 V. 225 KW.

Electroplating, 4000 amp., 9 volts

4 circuit Battery Charger. Each circuit 120 volts, 180 amps.

Seletron and Germanium Division

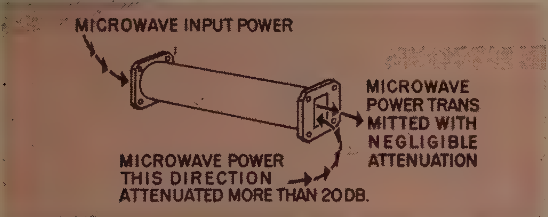
RADIO RECEPTOR COMPANY, Inc.

In Radio & Electronics since 1922

SALES OFFICE: 251 WEST 19th STREET, NEW YORK 11 • FACTORIES IN BROOKLYN, N. Y.

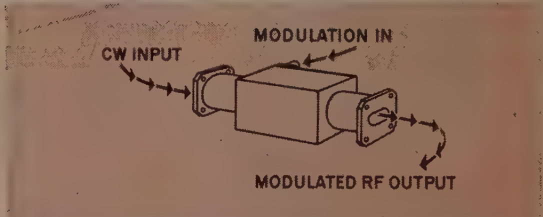
THE MICROWAVE FERRITE DUO

THE UNIDIRECTIONAL TRANSMISSION LINE



The Uniline section is a new development specifically designed for use in test measurements particularly where the impedance of the load is variable. For example, one of the several possible applications for the Uniline is as a replacement for the loss-type attenuator commonly used for isolation between source and load. In this instance, very substantial isolation is provided with negligible loss in transmitted power. Up to 100 times as much power is available for test purposes when the Uniline is used. The Uniline is a truly non-reciprocal transmission line element, not a directional coupler.

THE MICROWAVE AMPLITUDE MODULATOR



This new ferromagnetic resonance device is essentially a continuously variable microwave attenuator controlled by an applied magnetic field. Amplitude modulation of a CW microwave signal may be obtained by varying the magnitude of the magnetic field by means of an external modulating source. The Gyraline thus permits the microwave oscillator to be operated on a CW basis to eliminate undesirable frequency modulation and double moding frequently present when one of the klystron elements is directly modulated. The Gyraline also offers many possibilities as an electronically controlled microwave attenuator.

TECHNICAL SPECIFICATIONS

FREQUENCY RANGES: (Five models available) . .
5900-6400, 6400-6900, 6900-7400, 8800-9600, 9600-10,400 megacycles.

ATTENUATION, FORWARD DIRECTION: Less than 1 DB.

ATTENUATION, REVERSE DIRECTION: 20 DB. (Approx.)

VOLTAGE STANDING WAVE RATIO: 1.3 : 1, (or less) either direction.

FREQUENCY RANGES: (Five models available) . .
5900-6400, 6400-6900, 6900-7400, 8500-9900, 9600-11,200 megacycles.

INSERTION LOSS: Less than 1 decibel . . . .

MODULATION FREQUENCY: Up to 3000 c.p.s. . .

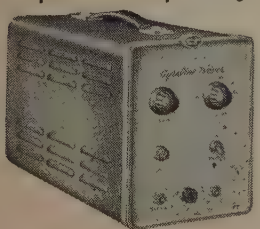
VOLTAGE STANDING WAVE RATIO:
1.4 to 1. (or less) . . . .

POWER HANDLING CAPABILITIES:
Maximum continuous microwave power dissipation, 2 watts . . . . .

COIL IMPEDANCE:
Nominal coil impedance at 1000 cps: 500 or 2000 ohms (either). . . . . .

D-92 AUDIO DRIVER FOR GYRALINE

Provides a flexible and convenient source of audio power for operating the Gyraline.



Circuit consists of an audio oscillator which provides sine wave modulation from 800 to 1200 cps. This oscillator drives an 8 watt output amplifier which is matched to the Gyraline coil. The gain of the D-92 Driver is sufficient to drive the Gyraline to greater than 90% modulation.

Complete information upon request.

Write for descriptive bulletins.

CASCADE RESEARCH CORPORATION
53 VICTORY LANE, LOS GATOS, CALIF.

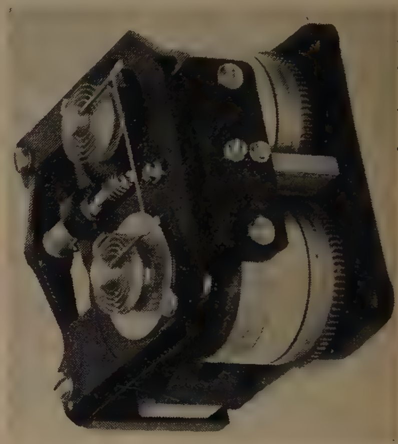
News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 50A)

Magnetic Fluid Clutch Meter/Positioner

Texas Instruments Inc., 6000 Lemmon Ave., Dallas 9, Tex., recently developed a sensitive and durable magnetic fluid clutch meter/positioner, which they now introduce for commercial use. It is used as a pen-recording meter movement in airborne military gear. The output shaft mechanism will deflect up to 120° with maximum rated output torque of 5.25 ounce-inches at 4 ma.

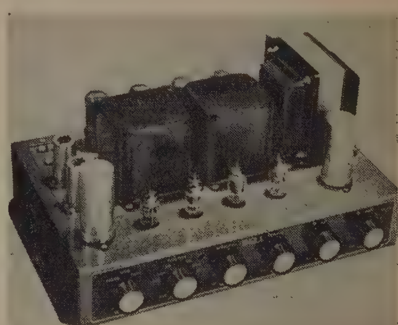


The movement combines smooth and precise performance, responding linearly to signals from 10 to 500 microamperes. It is accurate to within 0.5 per cent and, as currently applied, has "flat" frequency response up to 5 cps. Life span is over 3000 hours.

The movement consists of two small magnetic fluid clutches (0.46 lbs each) geared to rotate in opposition with their output shafts linked. The output shaft mechanism responds to the resultant developed torques of the clutch input coil signals.

Binaural Amplifier

A binaural amplifier complete with self-contained power supply, preamplifiers, and controls, has been announced by **Bell Sound Systems, Inc.**, 74 E. Long St., Columbus, O.



The latest addition to Bell's line is model 3-D, which includes three dual sets of inputs, one set for either radio or tape,

(Continued on page 65A)

News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 64A)

and two sets for phonograph records which provide for use of either high or low magnetic pickups, and are equalized specifically for all existing binaural records.

The unit is designed so it may be used for monaural reproduction of conventional broadcasts, records or tapes through one or both channels. In addition to a three-station input selector, the unit has a six-position function switch to select binaural, monaural, or reverse binaural either with or without volume control. A balance control permits the operator to compensate for differences between loudspeakers, pickups, and listening areas in order to restore the original binaural balance. Boost and attenuation are incorporated into the design of the bass and treble controls. A master gain control is used.

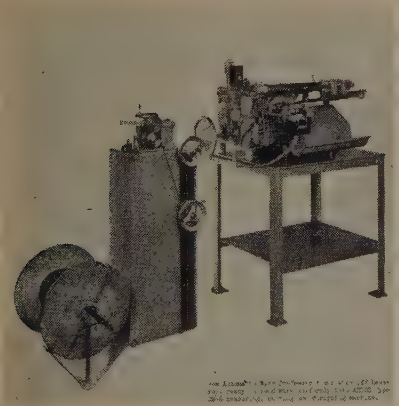
Power output is 20 watts (10 watts each channel) at less than 0.5 per cent total distortion. Peak power is 35 watts.

Frequency response is 20 to 20,000 cps $\pm\frac{1}{2}$ db (Tone controls set for flat response).

Hum level is 70 db or more below rated output.

Wire Prefeeder

Artos Engineering Co., 2757 S. 28 St., Milwaukee 46, Wis., has developed an automatic wire prefeeder for users of large or heavy reels in their wire measuring, cutting and stripping machine operations.



The AE-266 is equipped with a scale for setting to the same reading as the scale on the stripping machine. To compensate for the slight difference in payout speed of wire in relation to the stripping machine, the prefeeder is intermittently speeded up and slowed down by solenoid action.

The prefeeder is powered by a $\frac{1}{4}$ hp single phase, 110 v motor. The coil in the starter for the prefeeder is energized from the control circuit of the machine. Therefore, the prefeeder will always start and stop with the stripping machine. The power supply for the $\frac{1}{4}$ hp motor and the two solenoids of the prefeeder is, however, separate and completely independent from the power supply for the machine.

(Continued on page 66A)

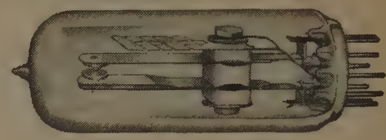
News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 65A)

Miniature Delay Relays

Amperite Co., Inc., 561 Broadway, New York 12, N. Y., now have their delay relays available in the miniature T6-½ Bulb-Base 9-pin miniature.



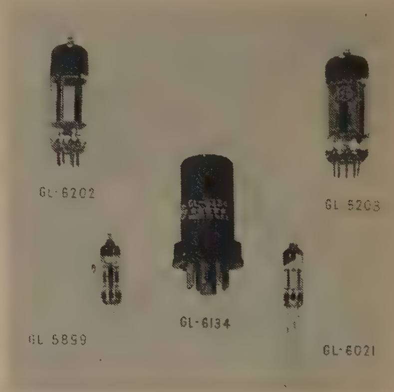
These tubes can be supplied for all standard heater voltages, such as 6.3–26 and 115 v. Delays are available from 2 to 90 seconds. Wattage consumed by the heater is approximately 2 watts. Contact rating: 115 v, 2 amperes ac, non-inductive. ambient compensated for temperatures range is from −50 to +70°C.

Hermetically sealed, the Amperite Miniature Delay Relays are not affected by altitude or any other climatic conditions. Their construction enables these miniatures to withstand vibration.

For further information, write to the company.

Five New Tubes

Addition of five new receiving tubes to the "Five-Star" high-reliability line manufactured by **General Electric Co., Tube Dept.,** Schenectady, N. Y., bring the total of available types to 31.



Specifically designed for use in equipment in which extreme electrical and physical dependability is essential, the newest group of "Five-Star" tubes includes a twin diode, two twin triodes, and two pentodes.

The GL-5899 is a subminiature, semi-remote-cutoff pentode intended for use as a wide-band, high-frequency amplifier. Its semi-remote-cutoff characteristic makes it suitable for use in circuits to which it is desired to apply automatic-gain-control.

The GL-6021 is a subminiature medium-mu twin triode suitable for use in general purpose amplifier applications. Each section has an individual cathode and is electrically independent.

The GL-6134 is a sharp-cutoff pentode intended for service as a wide-band rf

(Continued on page 74A)

Polarad

COLOR TV

equipment for studio and laboratory

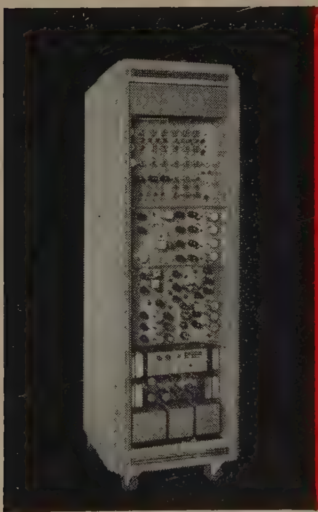
Polarad NTSC Color TV Equipment consists of fully integrated units that combine ease of operation with maximum flexibility.

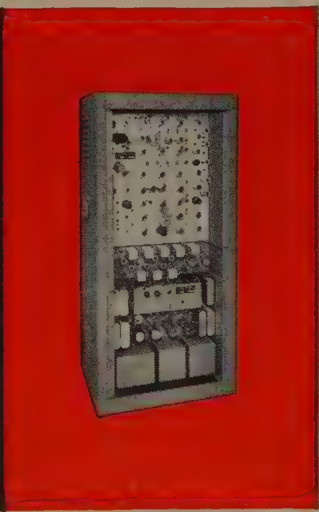
COLOR BAR GENERATOR—PT-203 Provides color TV test signals, NTSC standards, for color TV equipment, networks and components. Supplies complete composite video signal in the form of seven fundamental color bars simultaneously with seven gradations of gamma bars. White dot pattern superimposed on both color and gamma bars. Color test pattern can be used for adjustment of both color transmitter and receiver circuitry. Internal switching permits 19 different test patterns.

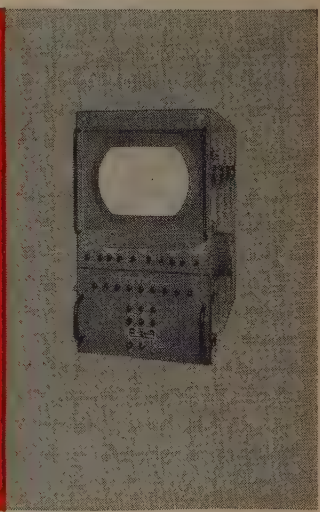
COLOR SYNCHRONIZING GENERATOR—PT-201 Furnishes NTSC color TV subcarrier frequency component and contains divider network to yield 31.5 KC signal. Provides driving, blanking and synchronizing pulses, as well as vertical and horizontal dots for linearity checks. Used to drive color bar generators, or any other NTSC color TV generating equipment. Utmost stability assured by driving all pulses from leading edge of crystal controlled oscillator. Unit may be locked to synchronize with 60 cps line. **Also available** as a separate unit, PT-202 Subcarrier Frequency Generator to modify any existing standard (B/W) synchronizing generator in accordance with NTSC color TV standards.

COLOR TV VIDEO MONITOR—M-200 Compact, rugged instrument consisting of two portable units. Uses 15 inch RCA tri-color Kinescope. Checks quality of NTSC color video signals in studio, on transmission or in factory. Excellent synchronizing stability. Displays highest definition transmitted pictures with exceptionally good color rendition. All controls on front panel. Instrument may be rack mounted or employed as field test equipment.

ALSO AVAILABLE An NTSC color TV Flying Spot Scanner, furnished as a completely packaged unit supplying a standard color video signal. For further information, contact your nearest Polarad representative or write directly to the factory.







COLOR BAR GENERATOR PT-203
OUTPUT SIGNALS: Composite Video
(2 outputs) (Sync. negative & positive)
SIGNAL INFORMATION
7 Bars of Color
7 Bars of Gamma Gradations
White Dot Pattern (Vert. and Hor.)
EXT. VIDEO INPUT FOR MIXING
2 Volts neg. polarity

COLOR SYNCHRONIZING GENERATOR PT-201
OUTPUT SIGNALS:
Synchronizing Signal (Neg.)
Camera Blanking Signal (Pos., Neg.)
Horizontal Drive Signal (Neg.)
Vertical Drive Signal (Neg.)
Composite Video Output (Neg., Pos.)
NTSC Color Subcarrier Freq.
(3.579545 mc/s)

COLOR VIDEO MONITOR M-200
Signal Polarity—Positive, Negative, Balanced
Input Video—0.25 to 2.0 Volts, peak to peak
Input Impedance—66 mmf across 2.2 megohms
Resolution—250-300 lines (Full Utilization of NTSC Color Signal Bandwidth)
Linearity—Better than 2% across raster Horizontal and Vertical

Polarad ELECTRONICS CORPORATION 100 METROPOLITAN AVENUE, BROOKLYN 11, NEW YORK

REPRESENTATIVES

Albuquerque • Arnprior, Canada • Atlanta • Boston • Chicago • Cleveland • Fort Worth • Kansas City • Los Angeles • New York • Philadelphia • San Francisco • Seattle • St. Paul • Syracuse • Washington, D. C.

News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 66A)

or IF amplifier, or as a video-amplifier Electrically and physically, the GL-6134 is a replacement for the 6AC7.

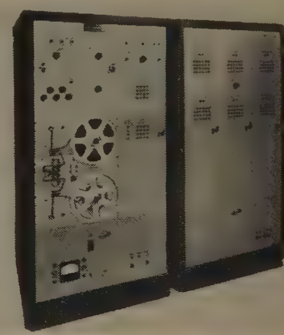
The GL-6202 is a miniature full-wave high-vacuum rectifier for use in power supplies in which the dc current requirements do not exceed 50 ma. Within the limits of its maximum ratings, it is a replacement for the 6X4.

The GL-6203 is a miniature full-wave high-vacuum rectifier intended for use in power supplies of ac and storage battery equipment.

Contact G.E. for application and performance data.

Digitizer and Magnetic Memory

A multi-channel data handling system for use in aircraft and missile testing has been completed by the **Potter Instrument Co., Inc.**, 115 Cutter Mill Rd., Great Neck, L. I., N. Y., for Consolidated Vultee Corp. of San Diego.



The new unit is designed to digitize sample, and record information obtained from Doepler-frequency effects or pulse-code modulation from each of three independent channels and to provide, through a fourth channel, recorded time marker signals as a data reference. Special decades are used to allow addition or subtraction of counts and to provide an indication of algebraic sign of the total counts.

"On the fly" reading provides a marked increase in the data handling capacity of the system by eliminating the necessity of alternating measurement and sampling cycles. This is accomplished without interrupting the measurement process.

An element in the data reduction process is the new Potter Digital Magnetic-Tape Handler which is used as the basic recording medium. High-speed and precise control of tape starts and stops permit recording of data from all four channels at high rates and playback at the slower speeds required to accumulate the information on tabulating cards, or for insertion into electronic computers.

Individual components or complete systems are now available to provide sampling rates to one hundred per second, and these may be combined with existing or proposed methods employing punched cards, direct data printers, or magnetic tape recorders.

(Continued on page 154A)

PROCEEDINGS OF THE I·R·E®

Published Monthly by
The Institute of Radio Engineers, Inc.

VOLUME 42 — *January, 1954* — NUMBER 1

THE PROCEEDINGS OF THE I·R·E

Contents continued, following page

Changes of address (with advance notice of fifteen days) and communications regarding subscriptions and payments should be mailed to the Secretary of the Institute, at 450 Ahnaip St., Menasha, Wisconsin, or 1 East 79 Street, New York 21, N. Y.

* Numerals in parentheses following Director's names designate Region number.

PROCEEDINGS OF THE I-R-E®

Published Monthly by

The Institute of Radio Engineers, Inc.

(Continued)

I-R-E News and Radio Notes Section

Advertising Section

Foreword

On July 23, 1953, the National Television System Committee petitioned the Federal Communications Commission to adopt its proposed signal specifications as the technical transmission standards for commercial color television broadcasting in the United States. On December 17, 1953 the FCC approved this petition. Compatible color television is now authorized to operate on a commercial basis starting the latter part of January 1954.

This momentous event follows by only two years publication of the first Color Television Issue of the PROCEEDINGS OF THE I.R.E. in October, 1951. Yet during this short interval Color Television has undergone drastic and rapid evolutionary changes. It has been a period of intensive efforts and formidable accomplishments on a scale that has rarely been witnessed by any industry or profession.

Basically important to the progress of this period has been the monumental work of the National Television System Committee. Formulation of signal specifications by the NTSC was a prodigious achievement requiring hundreds of thousands of engineering man-hours voluntarily contributed by the most highly skilled engineers and scientists in the radio-electronics and allied industries, and with the approval of their organizations. As a result of this work, a number of important concepts have been developed concerning the generation, transmission, and utilization of the NTSC signal, the substance of which is described in technical monographs prepared by the NTSC. These findings, in turn, have enabled industry to make many notable advances in color television equipment and techniques in the last few months.

It is the purpose of this second Color Television Issue of the PROCEEDINGS to present a full account of these many recent developments in the field of color television. Before turning the reader over to the wealth of material that follows, a brief outline of the contents of this issue might be of interest.

The papers in this issue have been arranged in two groups. The first group comprises twenty-two contributions originating from the NTSC and its officials. Much of this material, in particular the NTSC monographs, was prepared by the NTSC for its own use and appears herein through the generous permission of that body. The second group of papers, twenty-eight in number, constitutes technical contributions submitted by individual workers in the color television field.

The issue begins with an informative symposium of four introductory papers, written by the Chairman and the three Vice-Chairmen of the NTSC, which will greatly assist the reader in understanding the nature and significance of the papers in this issue. This is followed by a brief description of the organization of the NTSC and scope of its Panels, the NTSC signal specifications as submitted to the FCC, and a discussion of the NTSC field test results prepared for these PROCEEDINGS by the three Panel Chairmen responsible for this important activity.

The remaining fifteen papers of this first group are devoted to the NTSC monographs and constitute the heart of the issue. In the first of these papers the purpose of the monographs and the scope of each is skillfully and clearly set forth in an introduction written by the Chairman of Panel 12 which was responsible for their preparation. There then follow the Panel 12 documents consisting of a nontechnical description of the NTSC standards followed by thirteen monographs.

The second group of papers in the issue covers, in the following order: colorimetry; cameras and film; color multiplexing; limitations and errors imposed on the signal by a color television system; measurement and correction of these errors; network transmission of color television; techniques for improving color receiver operation; color picture tubes and associated circuits; color receivers; a bibliography, including summaries, of all papers previously published by the IRE on color television.

This issue is presented to the membership in the belief that it will provide a basic reference to the subject of color television for many years to come and, in combination with the first Color Television Issue (copies of which are still available), will present most of what is now known in this field.

—*The Administrative Editor*

William R. Hewlett

PRESIDENT, 1954

William R. Hewlett was born on May 20, 1913 at Ann Arbor, Michigan. He received the A.B. degree from Stanford University in 1934, and the M.S. degree from the Massachusetts Institute of Technology in 1936. In 1939 he received the E.E. degree from Stanford University, after spending the period from 1936 to 1938 engaged in electro-medical research in Palo Alto, California.

In 1939, Mr. Hewlett joined David Packard in starting the Hewlett-Packard Company, for the manufacture of electronic test equipment, in Palo Alto. During World War II he was on active duty with the Army, first assigned to the office of the Chief Signal Officer as Officer-in-Charge of the Research Section, and later as a member and finally Officer-in-Charge of the Technical Staff of the Engineering and Technical Service. This work involved staff responsibility for the research and development program of the Signal Corps. He was then assigned to the New Developments Division, War Department Special Staff, as Officer-in-Charge of the Electronics Section, in which position he was responsible for co-ordinating and expediting the electronic program of the Army. Since 1946, Mr. Hewlett has been associated with the Hewlett-Packard Company as co-manager, and he has taken an active part in the research developments of the company.

Mr. Hewlett became a Student Member of the IRE in 1935, an Associate in 1938, a Senior Member in 1947, and received the Fellow Award in 1948 "for his initiative in the development of special radio measuring techniques." He has been a Director of the IRE since 1950, and was Chairman of the San Francisco Section in 1949–1950. He has also been active on many of the IRE committees. He is a member of Sigma Xi, and the American Institute of Electrical Engineers.

Alfred N. Goldsmith

EDITOR EMERITUS

Under the guidance of Dr. Alfred N. Goldsmith, the PROCEEDINGS OF THE I.R.E. has become a world-leading publication in engineering and scientific circles and the publication activities of the Institute have rapidly expanded. A co-founder, Fellow, and Life Member of the Institute of Radio Engineers, he has served as Editor every year but one, President for one term, Secretary for ten years, and has been a Director of the IRE continuously since its inception in 1912. In recognition of his distinguished service he has been appointed Editor Emeritus as of January 1, 1954.

Dr. Goldsmith is noted equally for his many technical contributions to the radio, phonograph, television, color television, and motion picture fields. He has been associated with the College of the City of New York since 1906 where he is associate professor of electrical engineering with life tenure. He has served as consulting engineer for the General Electric Co., 1915–1917; Director of Research, Marconi Wireless Telegraph Co. of America, 1917–1919; held the positions of Director of Research, Chief Broadcast Engineer, and Vice President of RCA during the period 1919–1933; and is now a private consulting engineer.

Dr. Goldsmith is the only holder of both of the highest IRE awards, the Founders Award, to be presented during the 1954 IRE National Convention, and the Medal of Honor. Among other honors he has received are the Modern Pioneer Award from the National Association of Manufacturers, the Townsend Harris Medal from the College of the City of New York, the Medal Award of the Television Broadcasters Association, and the Radio Pioneers Special Citation. He holds membership in numerous engineering and scientific societies and is a past president of the Society of Motion Picture and Television Engineers.

W. R. G. Baker

Chairman

National Television System Committee

The Future of Color Television*

W. R. G. BAKER†, FELLOW, IRE

A full understanding and appreciation of the many developments reported in this issue would not be possible without some prior knowledge of the evolution of color television, the technical and economic factors which affected its course of development, the role played by the National Television System Committee in bringing about these developments, and the likely future progress of color television and its effect on the manufacturer, the broadcaster, and the viewer.

To provide the readers of this special issue with this helpful background information, an important series of five introductory papers has been prepared by the Chairman of the NTSC, its three Vice Chairmen, and the Chairman of the Panel responsible for the production of the NTSC monographs. The first four of these informative discussions, written by W. R. G. Baker, E. W. Engstrom, A. V. Loughren, and D. B. Smith, respectively, appear in the immediately following pages. The fifth paper of the series, by D. G. Fink, Chairman of NTSC Panel 12, appears on page 43 of this issue immediately preceding the NTSC monographs which it so ably introduces.—*The Administrative Editor.*

THIS ISSUE of the PROCEEDINGS is in large part a report on the various technical aspects of the standards for color television developed by the NTSC in the period from 1951 to 1953. Many of the papers presented here are the work of NTSC Panel 12, which was charged with the task of preparing technical monographs describing the new scientific concepts evolved by the NTSC in its work. In addition, a number of other papers relating to color TV are included because of their fundamental importance. Altogether, these papers contain the most complete and authoritative technical description of the NTSC standards for color television yet made generally available.

In its work on color, the NTSC has repeated its earlier achievement in the development of standards for monochrome TV, which has been described as "The scientific development of the highest standards within reach of the industry's experts." Let me emphasize that this achievement is not just the development of standards for a color system as such; several of the other color systems proposed were capable of good color performance. What is unique in the NTSC standards is the manner in which they solve the many difficult problems involved in all phases of color broadcasting, networking and reception, while introducing a color service which will be a partner rather than a competitor of the firmly established monochrome service. This achievement was no accident. The wide membership of the NTSC included foremost experts in all fields of television. Consequently, no aspect of the system was slighted. No part of the final standards was accepted without being tried and proven in careful experiments and exhaustive field tests. The unanimity with which these standards were finally adopted by the NTSC is a tribute to the care that went into framing them.

The general principles followed throughout the work of the NTSC were formulated by an Ad Hoc committee, which in 1950–51 made a detailed study of the color TV work going on in the laboratories of several of its members. As a result of this study, the committee made the following recommendations concerning the form of the color system:

The luminance, or "brightness," component of the color picture should be transmitted according to present monochrome standards, so that it might be received as a monochrome "base" picture of quality comparable to present monochrome pictures. The additional "coloring" information should be transmitted simultaneously in the form of two independent signals modulating a single subcarrier which is located in the video band of the monochrome signal. The subcarrier frequency should be so located with respect to the video carrier that any interference it produces with the monochrome signal will have a minimum visibility. A color synchronizing signal, required by the receiver for proper detection of the color subcarrier, should be added to the present sync signals during an interval available under the present standards.

The subsequent work of the various panels of the NTSC was concerned with determining by analysis, experiment, and field tests the most practical and best parameters for such a system. Two results were sought:

1. To achieve the highest possible quality of color service through the choice of signals which, by matching the characteristics of color vision, allow the transmission of a visually high quality color picture with a maximum economy of bandwidth, and

* Decimal classification: R583. Original manuscript received by the Institute, November 6, 1953.

† General Electric Co., Syracuse, N. Y.; Chairman of the National Television System Committee.

2. To insure a continuing monochrome service of quality equal to the present one by transmitting the additional color signals in such a manner that they do not interfere with proper operation of unmodified monochrome receivers.

That these aims have been achieved is of the highest importance for an economically healthy transition from monochrome to color service. The high quality of the color system will encourage sponsors, broadcasters, and a substantial portion of the viewers to convert to color as rapidly as possible. The compatibility between monochrome and the color service means that the transition will require no sacrifices on the part of either broadcaster or viewer. The owner (or prospective buyer) of a monochrome set is insured against obsolescence even though all his stations convert to color transmissions, while the color set buyer will be able to receive monochrome programs from local stations not yet converted. Then, in addition the broadcaster can gain an additional color audience without inconveniencing his monochrome following. While the purchase of color cameras and studio equipment of his own will require a substantial investment, he can obtain the additional equipment necessary for putting network color shows on the air with relatively little expense.

For these reasons, we should see a very smooth and rapid transition to color broadcasting, limited only by the availability of the necessary equipment. The major networks now have color cameras and studio equipment, so they stand ready to put at least part of their programming into color as soon as FCC approval is granted. (Such approval was granted by the FCC on December 17, 1953.) For the local broadcaster, there will be available in the first quarter of '54 the monitoring and conversion equipment necessary to modify his transmitter for color. If he wishes to originate color broadcasts from film, he will be able to purchase, sometime in the second quarter of '54, the necessary color scanners for still and motion pictures, and the color pulse generator and multiplexer for producing the NTSC signal. He will have to wait somewhat longer for a complete color camera chain; these should be available during the last half of '54. During '54, most of these items will be produced on a model shop basis and so will be available in limited quantities until regular production starts in early '55.

The transition to color production will cause a somewhat greater upheaval for the receiver manufacturer. Unlike the manufacturer of studio and transmitter equipment, he must plan to divide his effort between his color and monochrome lines for the next few years. Since it has been estimated that color sets will require about twice the production facilities required for monochrome sets, this will mean a considerable expansion in terms of space, equipment, and personnel. While most manufacturers have produced a number of experimental and preproduction color sets, the tooling-up for quantity production is only in progress. Consequently, it will be 1955 before color set production reaches an appreciable fraction of the present monochrome output.

The most important single factor in the production of color sets is the color tube itself. A number of promising types of color tubes are in the development and early production stages; only time will tell which type will give the best performance and economy. It is likely initial production of color sets will be limited by the rate at which color tubes can be produced, and also that the cost of early sets (estimated at from two to three times the cost of a comparable monochrome set) will be due largely to the presence of the expensive color tube. Continued development and mass production of color tubes will result in substantial reductions of this cost, until eventually color sets may be sold for perhaps 20–30 percent more than monochrome sets of equal quality.

The development of color tubes will be matched by corresponding advances in the circuitry of color receivers. A color set performs more functions than a monochrome set, and is necessarily more complex. However, we can expect to see the development of simpler, cheaper, and more reliable circuits and components to solve the special problems of color. In the detection of the chroma information, for example, a special purpose tube can perform operations requiring several conventional tubes. It is also possible to imagine a new type of color tube which will simplify, and maybe even participate in the process of decoding the color signals. From our experiences with monochrome television, we can predict that such developments will be carried out, and will result in decreased costs, greater reliability, and better performance of color receivers.

In recent years, television programming has become more and more dependent on the use of film. Film, therefore, should continue to play an important role in programming for color. While direct-film transmissions of satisfactory quality have been made with conventional color film, the use of this film for color kinescope recordings does not at present give entirely satisfactory results. One difficulty is that because color television uses an additive and the film a subtractive color process, the weaknesses of both systems tend to overlap and produce a general degradation of quality. It is felt that this difficulty is not a basic one, since in designing a film specifically for color television recording the film manufacturer is freed from many hampering restrictions. For example, his film need not be a true color picture of the recorded scene as long as it contains the "color" information in recoverable form. Video recording using magnetic tape is another possible solution to this problem.

To turn from the technical aspects of color to its impact upon programming, it is only necessary to visualize some present programs when transmitted in color.

Recently, I observed a group of children engrossed in watching the fine show "Zoo Parade." The show originated in the bird houses of the zoo, and as Marlon Perkins introduced one exotic bird after another, striving to convey impressions of the brilliant plumage of one, or the subtle gradations of color on another, I was forcibly impressed with what a boon color will be for him. The programming of educational shows of all sorts has increased in scope and excellence over the past few years; color is the logical next step in their advance. Not just the plumage of birds, but the exhibition of great objects of art, the clothes in a fashion show, the paraphernalia of scientific demonstrations all cry for the added dimension of color.

But there is need for a word of caution. To many monochrome programs, making up the greater percentage of shows on the air today, color will add little. Most dramatic shows, mystery plays, audience participation programs, undoubtedly will continue to be telecast in black and white. On the other hand, variety shows, special events programs will gain added impact and give greater enjoyment through the use of color.

The addition of color to television, will do more than increase enjoyment of the viewing public. It will bring another "dimension" to television, thus making television even more useful for a much underrated function of television, the marketing of goods and services. It must be remembered that creating the urge to buy is an important factor in an economy which is dependent on the rapid flow of goods and materials from their source to the consumer.

The addition of color to television whether through compatible color for broadcast purposes or through noncompatible color for closed circuit industrial use, increases the value of television. Educational television should benefit greatly by color, increasing the number of subjects that can be taught and adding to the effectiveness of the media. Many new applications for industrial television are created through the addition of color. Color is of prime importance in steel mills, or in viewing chemical processes, or in atomic energy installations in which color coding is utilized. These are a few of the benefits of color television not recognized at a casual glance.

But color will not result in a revolution within the electronics industry. There will be, I feel, an evolutionary period but this will not obsolete monochrome nor entirely replace it.

Color television is one of the greatest technical achievements of our age. It represents outstanding progress and another important contribution of the electronics industry to better our American way of living.

Basic Concepts and Evolution of Color Television*

ELMER W. ENGSTROM†, FELLOW, IRE

THE BASIC PROBLEM has been to develop a color television process which will not only reproduce the varying intensities of light and shade in a scene with a quality comparable to that of the black-and-white television process but will also produce an image in colors pleasing and convincing to the viewer.

Two other conditions have been of major concern. In the orderly progression of developments, television in black-and-white preceded television in color. First, therefore, color television had to develop within the framework of the existing black-and-white service in order to effect a smooth transition from black-and-white to color broadcasts. The signal specifications for color must, therefore, be compatible with black-and-white television. They must insure that color signals produce satisfactory black-and-white pictures on normal unmodified black-and-white receivers. The receivers designed for color must similarly produce satisfactory black-and-white pictures when tuned to a transmitter broadcasting black-and-white signals.

Color television must be provided in an already limited frequency spectrum. Second, therefore, the color-television service must be able to operate within the six-megacycle channel allocation set by the Federal Communications Commission for black-and-white service.

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† RCA Laboratories Div., Princeton, N. J.; Vice-Chairman of the National Television System Committee.

This requirement became increasingly evident with time, as the black-and-white service came into wider use. For color television, much more information must be transmitted than for black-and-white. The method utilized must be one whereby this additional information can be transmitted within the same bandwidth. It must, therefore, utilize the frequency spectrum more efficiently than the present black-and-white service.

How much information has to be transmitted and how can this be done? The consideration of this question involves the science of seeing and color. Scientists in this field showed long ago that visual sensations produced by viewing most natural objects may be duplicated by viewing mixtures of light of three primary colors in the proper proportions. A color television system based upon this principle alone would require the equivalent of three monochrome systems.

At this point it appeared that there were two alternatives: either a channel wider than six-megacycles would be required or reduction in resolution, increase in flicker or both. As black-and-white television service developed, it became evident that the undeveloped ultra-high-frequency band would be required for black-and-white as well as for color. It then came to be realized, both by the television industry and by the Federal Communications Commission, that channels wider than six-megacycles for color could not be allowed. It was felt by some that the necessary sacrifice in resolution and in flicker would be allowable in return for color, and incompatible field-sequential color-signal standards were approved by FCC on this basis. Prior to, during, and following the adoption of these field-sequential standards, consideration of further refinements in the science of color television and an application of multiplex communication methods indicated and provided a better way, whereby the amount of information to be transmitted could be reduced without perceptibly harming the visual effect and whereby substantially greater efficiency in bandwidth utilization could be achieved in transmitting that information.

The basic principle of three-color reproduction applies only to the viewing of large areas. For sufficiently small areas, adequate reproduction may be obtained with mixtures of two colors. Furthermore, the seeing of really fine detail is devoid of all color perception. Thus, by providing three-color presentation of information relating to large areas, an optimum two-color presentation of information relating to smaller areas, and a presentation of the fine detail without color information, the amount of information to be handled, while greater than for black-and-white, is substantially less than three times greater. Using a novel system of multiplexing the brightness and color information which further increases the efficiency of bandwidth utilization, a six-megacycle channel may be used.

The foregoing method, thus simply explained, was the final result, but it was achieved by a step-by-step process of learning more about the actual requirements of color perception and then finding better electronic means for satisfying those requirements in less spectrum space.

The first step was a method of utilizing the fact that in three-color reproduction the same resolution is not required in all three components.

A second step was the limitation of three-color reproduction to large areas, and the utilization of monochrome transmission (mixed highs) for fine details.

An improved method of spectrum utilization was a third step. This involved the use of a color carrier suitably related in frequency to the line scanning rate. The color information is carried by multiplex modulation of this carrier while the brightness information is carried by direct video components as in black-and-white television. The energy of these direct components is distributed at discrete locations in the frequency band, leaving room for the color carrier and its color-signal energy sidebands between these locations.

Even with these advances, there was still too much information for a six-megacycle channel. This resulted in a minor degradation of color quality called color cross talk. A further step was the development of electronic means for minimizing the visual effect of this cross talk (color phase alternation). This procedure, however, had other somewhat undesirable effects. The fourth step then became the utilization of two-color reproduction for the middle portion of the video band involving visual areas small enough so that three-color reproduction was not required. In this way the bandwidth requirement was held to six megacycles without cross talk.

These steps are not independent nor were they taken in simple time sequence as related above. Actually they were considered together and for overlapping periods, along the general line of evolution indicated.

The evolution outlined above has met at each step the requirements stated at the outset, that in qualities applicable both to black-and-white and to color, the color picture should be comparable to current black-and-white service. Specifically, the field repetition rate and hence the large-area flicker were kept the same. Likewise the image sharpness and resolution remained visually equivalent.

In the formulation of signal standards for a broadcast service, such as color television, one is concerned with a basic and comprehensive approach. One seeks to specify only those characteristics which determine quality of performance and universality of reception from all transmitters. From the regulatory point of view, one specifies those characteristics which concern the channels to be assigned in terms of efficacy of use and least possible interference. All other matters should remain

broad and open in order that progress may be made in methods, apparatus and performance. The setting of optimum signal specifications is a matter that calls for sound engineering judgment and clear vision. On these decisions hinge the lasting value of the service. The word engineering as here used includes in its meaning good and practical economics.

Thus, while all signal specifications have been expressed in terms of scientific and technical requirements, the final embodiment must envisage the practicable, the achievable. One must try one's concepts by simulation and extrapolation. One must try by building apparatus representative of the state of the art. One must assemble a system of apparatus and field test the performance, estimating the future potentials. There, then, is the bridge to be crossed between the signal specifications or the standards and the apparatus or the system.

For color television, the National Television System Committee has agreed upon signal specifications to form the basis for standards. These take into account the characteristics of vision and satisfy the requirements of the viewer. They include the specifications of required channel width and propagation conditions for a broadcast service.

What then is the correlation between these signal specifications and current apparatus designed to operate on them? How does a system using these standards perform? What are the potentials for the future?

Apparatus, system research, and development for color television have extended over a period of time with continued field testing of results. It has been proved by extensive field tests that apparatus of satisfactory performance can be built to operate on these standards.

The signal specifications agreed upon are optimum. They have not been limited by the performance of current equipment, and they do permit future advances in apparatus simplification, system performance, and stability of performance. We may look forward, within the scope of these specifications, to increased flexibility of facilities for producing color-television programs. We may look forward to color-television receivers of lower cost providing larger and brighter pictures. This is the horizon for the color system and apparatus that the researcher, the manufacturer, and the broadcaster view. Ingenuity and invention will have full sway within the compass of standards now achieved.

On a solid foundation of good standards and system possibilities color television can grow to serve all.

Psychophysical and Electrical Foundations of Color Television*

A. V. LOUGHREN†, FELLOW, IRE

Summary—**The foundations for engineering advance consist of quantitative knowledge of the nature of the need to be served and knowledge of the new principles needed to serve the need. The nature of these foundations for color television, and their possible consequences in other arts are presented.**

THE STRUCTURE of color television is erected in large part on foundations identical with those which support successful monochrome television broadcasting. The addition of color makes the television structure more weighty and more extensive, and it seems in order to inspect the additions to the foundation upon which engineers are relying to carry this added structure.

The foundation for any sound engineering achievement consists of two parts: first, there must be an adequate understanding of the need to be served and a statement of the several aspects of that need in quantitative engineering terms; second, the principles and the techniques which may be usefully applied to the meeting of the need must be recognized and understood.

The Needs

The first thing one observes in studying a color television picture is that new kinds of information must be added to the picture as compared to a black and white picture. It had been established, many decades ago, that three kinds of information were perceptible to the human eye when uniform colored surfaces were viewed. The technique of visual color measurement, or colorimetry,[1] which is based on this three-fold nature of color vision, had been brought to a high state of perfection and was available for the use of the color television system engineers.

* Decimal classification: R583. Original manuscript received by the Institute, October 23, 1953.

† Hazeltine Corp., Little Neck, L. I., N. Y., and Vice-Chairman of the National Television System Committee.

[1] For an excellent introduction to colorimetry, and further bibliography, see W. T. Wintringham, "Color television and colorimetry," Proc. I.R.E., vol. 39, pp. 1135–1172; October, 1951.

So three kinds of information must be transmitted for a color picture as compared to only one kind for monochrome. But how much information of each kind is needed if the resulting color picture is to be acceptable? This question received little attention in the television art until rather recently (although a limited amount of relevant information had been developed out of studies of visual acuity). The work of A. V. Bedford[2] and the subsequent work of Panel 11 of the National Television System Committee[3] furnish reasonably conclusive support to the following view: taking as a standard a monochrome television picture which makes effective use of a 4 megacycle pass band, and choosing as the three kinds of information to be transmitted for color purposes the luminance and two components of coloring, if the color picture uses the same 4 megacycle luminance bandwidth as that employed for the monochrome picture and employs bandwidths of only 1 megacycle for each of the two coloring components, it will appear just as sharp as the black-and-white picture.

Later work in several laboratories, whose composite results are reported elsewhere[4] in this issue of the PROCEEDINGS, has established the fact that choice of one of the coloring components to indicate color along the path "yellowish green-gray-magenta" permits a further reduction in the bandwidth of this particular component to about one half-megacycle without impairment of the resulting picture.

The eye is thus seen to make a greater demand for luminance information than for coloring or chrominance information.

There is another respect in which the nature of human vision makes a more severe demand upon the luminance information channel than on the channel for the chrominance information. Momentary disturbances to the picture, which may be caused either by some residual mutual interference between the several components of a single transmission or by interference from an unwanted transmission, are relatively easily perceived if they occur in the luminance information of the picture but much less easily perceived if they affect only a chrominance component; this observation appears to be valid whether the disturbance is momentary only or is periodically repeated. While this property of human vision had been known in a general way for a long time from studies of flicker and from the use of the flicker photometer, B. D. Loughlin appears to have first perceived its significance in the color television problem and in particular, its implication that minimum perceptibility of disturbances of many sorts would result if the transmission system and the receiver apparatus were designed to favor the protection of the luminance component of the signal against interference at the expense of some impairment to the signal to interference ratio of the chrominance channel.[5]

The needs enumerated thus far have all been psychophysical in their origin. Two further items, differing in character but comparable in importance, should also be mentioned. The first of these is the extreme importance of conservation of the radio spectrum; if acceptable color television pictures could not be broadcast within a 6 mc channel, the prospect for bringing this new service to the public would become quite remote. The second item is concerned with the relationship between the existing highly successful monochrome television broadcasting system and the new color system: if this relationship is such that the signals of each system are receivable acceptably on the receivers of the other system, monochrome TV becomes the springboard for color; if this condition of mutual utility of the respective broadcast signals, called compatibility, is not fulfilled, color television must go through the same o ng slow growing period that was experienced by monochrome television, with the additional handicap of a competitor which monochrome television didn't have, namely monochrome television itself.

To summarize the needs, one may say that to the existing 4 mc band of luminance information contained in a monochrome transmission two further kinds of information, requiring in the aggregate $1\frac{1}{2}$ mc of equivalent channel width, had to be added without departing from the 6 mc total channel width or departing from effective interchangeability of transmissions with the monochrome system.

The Available Techniques

The principles and techniques which are now being introduced for the first time in order to make possible color television broadcasting have been known, at least in theory, for a considerable period. For example, Frank Gray[6] showed over twenty years ago that under proper conditions two television pictures could share at least the major portion of their bandwidth in common without objectionable interference between them; again, it has been known for many years that under proper conditions a single carrier could transmit two modulations simultaneously, one of these being in phase and the other in amplitude, without objectionable interference developing between the two. But it is a tremendous step

[2] A. V. Bedford, "Mixed highs in color television," PROC. I.R.E., vol. 38, pp. 1003–1009; September, 1950.

[3] K. McIlwain, "Requisite color bandwidth for simultaneous color-television systems," PROC. I.R.E., vol. 40, pp. 909–912; August, 1952.

[4] G. H. Brown, "Choice of axes and bandwidths for the chrominance signal in NTSC color television," PROC. I.R.E., this issue, pp. 58, 59.

[5] B. D. Loughlin, "Recent improvements in band-shared simultaneous color-television systems," PROC. I.R.E., vol. 39, pp. 1264–1279; October, 1951.

[6] F. Gray, "Electrooptical Transmission System," U. S. Patent 1,769,920, July 8, 1930.

from the knowledge that these things are theoretically possible to the recognition that they are usefully applicable to the problem at hand; and it is a further great step to learn all of the requirements which must be satisfied to carry out the application successfully.

Putting these principles into effective use has required tremendous amounts of apparatus and circuit development already, and great continuing effort will be needed to bring the several pieces of apparatus into as advanced a state as the basic design of the color signal now appears to have been placed. Work on cameras and other pickup devices, on transmitter signal processing circuits, on receivers and receiver circuits, and on receiver display devices will go on for many years and will continue to show advancement. To present any picture of all of this past work is not only beyond the scope of this short article, but perhaps beyond the scope of even this large issue of the PROCEEDINGS.

WHAT THE FOUNDATION PROVIDES

The broadcasting of color television signals by a system based on the principles here discussed provides a signal for standard monochrome receivers which is the effective equal of normal monochrome broadcasts. The color transmissions may contain all of the color information which the eye can usefully perceive at a normal viewing distance, and the information is present in such form that the normal service area of the broadcast station for color transmissions will be equal to its service area for monochrome transmissions. Further, since the luminance information is transmitted alike for color and monochrome pictures, a color television receiver can without readjustment by the viewer receive a monochrone transmission properly.

The work of the NTSC and of the contributing organizations to its has brought into practical use many techniques which were previously not practically available. That these new techniques will make early and important contribution to progress in other fields seems certain; and I think here particularly of such fields as the study of human vision, the color photographic art, the graphic arts generally, and the use of television for purposes other than entertainment.

The NTSC: An Exercise in Technical Co-ordination*

DAVID B. SMITH†, FELLOW, IRE

THE DEVELOPMENT and introduction of any new product or service is a process fraught with considerable hazards to the entrepreneurs promoting it. In addition, establishing a new broadcast service provides some special problems unique to mass communication. These stem from the fact that, first, any such service must use part of the radio spectrum, which is public property, and second, the technical facts of life require considerable co-ordination between the transmitter and the receiver. The more complicated the service, such as television, the greater the interdependence.

The common link between the two is the radiated signal. Hence both the character of the broadcast signal, and the meaning or information content of its several forms of modulation must be clearly understood. In addition considerable simplification of apparatus, especially at the receiver, may be effected if the possible variations of the signal are bounded. The above-defined body of knowledge is known as the "transmission standards" of a service. These standards then define a complete system. In a well conceived system, various different kinds of terminal apparatus may be used for both transmission and reception.

The question then arises as to how to determine an optimum system or set of transmission standards. What are the criteria by which one judges the merit of differing proposals?

The present Communications Act of 1934 contains a provision dating back to the first Radio Act giving the Federal Communications Commission the authority over broadcast stations:

> "To regulate the kind of apparatus to be used with respect to its external effects and the purity and sharpness of the emissions from each station, and from the apparatus therein."[1]

This has been generally accepted as giving the FCC the sole and final authority to establish transmission standards. The Commission, in general, does not create standards for new systems but rather determines to accept, modify or reject standards proposed to it by various interested parties. The Act, however, is not at all specific as to the criteria to be used in this judgment, other than the very general provisions requiring the Commission to act in the public interest.

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† Philco Corp., Philadelphia, Pa., and Vice-Chairman of the National Television System Committee.

[1] The Communications Act of 1934, section 303 (e).

The Commission was first faced with this problem in connection with television in the late thirties. It then established a Television Committee which recommended among other things that:

"It is universally agreed that the ultimate objective is to obtain standard performance from licensed television transmitting stations so that every receiver operated by the public will be capable of receiving every transmitting station within range everywhere in the United States."[2]

This basic philosophy, in broad terms, defines the scope or extent of transmission standards. It requires that all characteristics of the system and of the radiated signal which are necessary to permit all receivers satisfactorily to work with all transmitters should be specified, but the specifications should be no more restrictive than is necessary to accomplish this objective.

In the same report, the Television Committee pointed out that there are three broad stages in the development of television; namely, (1) Technical Research, (2) Experimental Operation, and (3) Commercial Service. It warned against premature setting of transmission standards stating:

"However, a serious question of public interest would arise in the future if the Commission should specify external transmitter performance capabilities differing from the operating capabilities of receivers in the hands of the public. This is because of the resultant possibility that the public's receivers would be incapable of receiving programs emanating from transmitters licensed by the Commission."[3]

and again:

"The danger involved in the premature adoption of any standards during the early stages of any technical development is one of retarding scientific progress. This is particularly true if such standards are inherently inflexible.

"Undoubtedly the public will desire to avail itself of future technical improvements as rapidly as inventive genius makes them possible. Thus, it would not be in the public interest for the Commission to specify rigid transmission requirements at an early stage of technical development, because to do so might result in a retardation of such development."[4]

This basic philosophy has likewise been wholeheartedly accepted by the large majority of the profession.

Finally it seems self-evident that any system should meet the requirement that it be economically sound and consistent with the American philosophy of a competitive broadcasting industry and a competitive transmitter and receiver manufacturing industry.

Hence the problem for the second NTSC to solve was to evolve a system and set of transmission standards for color television meeting the above requirements. It would have to establish a common point of view among such diverse groups as broadcasters, receiver and transmitter manufacturers and common carriers, and resolve the diverse interests of individual companies within the industry. And throughout its proceedings it would have to maintain clearly in mind that the interest of the public was paramount and unless it served the public well, its work would be for naught.

The basic plan of organization of the first NTSC, elsewhere described in this issue, was adopted because it had been eminently successful in the development of standards for black-and-white television. Under this plan the various specific technical problems were assigned to panels headed by men of considerable stature and competence in our profession and with panel membership open to all interested and competent people. In this manner, each technical problem was thoroughly discussed from all points of view. The final conclusion, then, on each issue would represent the consensus of the best thinking on that point in the industry. Moreover, no conclusion was reached until the problem had been thoroughly discussed, and in many cases many experimental tests made to obtain the data necessary for the conclusion.

In the case of color television, the work of the Ad Hoc Committee on Color Television[5] served to crystallize the basic philosophy of what was to become the NTSC system of color television throughout the industry, but there were still substantial differences of opinion among the several companies active in color television research, and there was no agreement as to detailed standards. The time was ripe for the orderly formulation and proof-testing of specific standards for a compatible color television system.

The NTSC was then reorganized to accomplish this objective. The first problem was to determine a set of tentative signal specifications for field test purposes. The second was then to field test signals in accordance with these tentative specifications to see how well they worked, and what unforeseen problems might arise and repeat this process until a satisfactory solution was obtained.

Following the pattern of the first NTSC, the first problem was subdivided into its major components. Panels were then organized to study each of these component parts and come up with tentative signal specifications for them.

[2] FCC, "First Report of Television Committee," Public Notice 34168, p. 5; May 22, 1939.

[3] *Ibid.*, p. 1.

[4] *Ibid.*, p. 10.

[5] See report of the Ad Hoc Committee on color television NTSC-AHCT-75; April 19, 1951.

Space will not here permit any description of the tremendous amount of effort expended and work accomplished by these and other panels later to be described. For this the reader is referred to the complete report of the NTSC filed with the FCC, or to the summarized description in the book, "Color Television Standards," to be published in the near future. It is not inappropriate to state here the writer's conviction that the industry owes a real debt of gratitude to the chairmen and members of these working panels.

The work of these several system panels was co-ordinated or supervised in the sense that it was necessary to see that the following had been accomplished:

1. That the proposed signal specifications were complete enough so that broadcasters could produce a signal which could be certified by various tests to meet the signal specifications;
2. That the signal specifications were complete enough so that receiver designers could design receivers which would accept the signal and reproduce the picture the broadcaster intended to transmit and with no misunderstanding as to what his intent actually was;
3. That the specification included all useful boundary conditions desirable to provide apparatus simplification but no restrictions which would unduly limit future apparatus development;
4. That the specifications were in fundamental terms and not in terms of specific apparatus;
5. That the specifications provided for the most efficient use of the radio channel in accordance with the best technical thinking at the time and were consistent with the broad economic requirements outlined above.

After the first phase was completed, the second, or field test phase, was begun. Here again the problem was subdivided into its major components, i.e., color broadcasting, color reception, and compatibility. Here again it was necessary to co-ordinate or supervise the several programs to ensure that the field testing was sufficiently thorough to provide all the information required by all the different interested parties.

In the main, of course, the field tests were designed to determine the following three basic characteristics:

1. That the color signals could satisfactorily be produced and transmitted by present television broadcast stations, and could be sent between stations by conventional intercity program channels, all with only reasonable modification of existing equipment plus the addition of special equipment needed for color, such as color cameras, etc.
2. That the color signals would satisfactorily operate color receivers throughout the normal black-and-white service area of present television broadcast stations, and that the receiver equipment necessary to utilize the signal was reliable and not unduly complicated.
3. That the use of the NTSC color signal by a broadcaster would not interfere with the normal black-and-white reception of his color signal on existing black-and-white receivers.

These basic requirements, however, had to be examined from several different points of view. For example, the Commission, in the general interest of the public, had to be assured as to the technical merit of the system and its status in the time scale of development. Did it provide pictures of acceptable quality? Would apparatus to use the signal be unduly complicated? Many questions of this nature were set forth by the Commission in various public notices on this subject. In addition, the Commission, in connection with allocation studies, needed considerable data with respect to coverage and interference characteristics. These and many other answers were required by the Commission for it to determine the merits of the system.

Receiver designers wanted to be satisfied not only that the proposed signals would be adequate for all kinds of receiving locations, but also that the method of reception was straightforward, reasonably simple, and one that would permit continued apparatus development and refinement. Receiver manufacturers wanted assurance not only that the new signal would not interfere with the continued enjoyment by their customers of receivers already sold, but also that the color system was sufficiently well-developed and proven so that they could have confidence in the performance capabilities of new color receivers. They wanted to make sure that the standards were sufficiently fundamental so as to provide for continuing development and simplification of their products.

The broadcasters needed assurance from these tests that they would in fact be able to broadcast these signals without interfering with their black-and-white service. In addition, they wanted to be sure that these were well understood measurement techniques by which they could determine whether or not they were producing a satisfactory signal and one which would produce on reasonably well-designed receivers, the kind of color picture they wanted to produce. They wanted to be sure this could be accomplished with reasonable apparatus. They, too, want assurance that the standards were in sufficiently fundamental terms so as not to handicap the further refinement and improvement of their equipment.

The common carriers had to satisfy themselves that the proposed signal was such that it could be transmitted by their equipment or reasonable modifications of it. They were concerned with such questions as: What changes would it require in their existing equipment programs? What modifications would it require in their various maintenance and standard operating procedures?

Various senior members of the profession, concerned with the system from the point of view of its basic soundness, had quite a few somewhat esoteric questions with respect to the fundamental, ultimate performance limitations, to which they required answers before they were willing to endorse the system.

Finally, nearly everyone involved in the program was concerned with the question (each from his own point of view): Is this new system likely to be a commercial success, and what more if any, can be done to insure that success? This last problem was not an NTSC problem except in the sense that commercial success usually lies in the direction of keeping things as simple as possible, avoiding undue complexity and unrealistic goals of perfection. These considerations were implicit in the NTSC counsels.

I think it manifest that no one individual nor one company, no matter how competent or well-intended, could bring to bear on the broad problem of standards, all the different points of view which should be considered. Only in a comprehensive organization, industry-wide in membership, such as the NTSC can this be done. Such an organization, if it is to accomplish its purpose, must of necessity be somewhat ponderous in its deliberations. Time must be taken to consider all opinions. There can be no "rule of cloture" in its meetings. Impatient men may sometimes chafe at the time required for seemingly endless debate, just as in larger world affairs the ostensible slowness of democratic parliamentary procedure is sometimes compared unfavorably with the undoubted speed but questionable soundness of the method of the dictator.

Television transmission standards, once adopted and put into practice, quickly acquire a bulwark of public investment in equipment requiring the standards, which makes them nearly impervious to significant change. Hence, the formulation and legal adoption of a set of standards for a new service is not a matter to be entered into lightly. The full and thorough discussion and deliberations of an organization such as the National Television System Committee, followed by the impartial and quasi-judicial review afforded by a rule-making proceeding before the FCC represent a time-consuming but nevertheless optimum method of arriving at such standards. This procedure might be considered an additional hazard in the establishment of a new service, but it is one well worth facing in order to assure the future success of that service.

National Television System Committee

Purpose: Charged by Board of Directors of RTMA to assemble technical data on: 1. Allocation of channels in the ultra-high-frequency band, 2. Procedures which will enable FCC to lift the "freeze" on very-high-frequency allocations, 3. Basic standards for development of a commercially practicable system of color television and to undertake such additional work as may be in the interest of providing more adequate television service to the American Public.

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VICE CHAIRMEN

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Dodds, Lawrence—Hazeltine
Estes, Robert N.—General Electric
McDaniel, Glen—RTMA
Richardson, Arthur—Sylvania
Uriell, Frank—Admiral
Werner, Robert—RCA

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Bendix Radio Division
Baltimore Sun
Columbia Broadcasting System
CBS-Columbia, Inc.
Chromatic Television Laboratories
Color Television Inc.
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Electronics-McGraw Hill
Emerson Radio and Phonograph
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Hallicrafters Company
Hazeltine Corporation
Hogan Laboratories
Magnavox Company
Motorola, Inc.
Philco Corporation
Radio Corporation of America
Raytheon TV and Radio Corporation
Sentinel Radio Corporation
Sylvania Electric Products Inc.
Tele King Corporation
Tele-Tech Caldwell-Clements Inc.
Westinghouse Electric Corporation
Zenith Radio Corporation

All Panel Chairmen and Vice Chairmen

PANEL 11—SUBJECTIVE ASPECTS OF COLOR

Alfred N. Goldsmith, Chairman
D. E. Hyndman, Vice Chairman
Scope: It will be the responsibility of this panel to determine, on the subjective basis, the efficient distribution of information as between brightness and color. This determination will take into account the subjective importance of the various constituents of a color picture. In addition, the panel will give due consideration to the requirement for a satisfactory compatible black and white picture from such a color transmission.

PANEL 11-A—COLOR TRANSCRIPTION

Alfred N. Goldsmith, Chairman
D. E. Hyndman, Vice Chairman
Scope: It will be the responsibility of this panel to study and report on methods of recording in color for television purposes, on methods of producing color release prints, and on methods and equipment for the utilization or transmission of color transcriptions.

COMMITTEE #1—Color Recording Methods and Materials

COMMITTEE #2—Color Release Print Methods and Materials

COMMITTEE #3—Color Transcription Television Transmission

PANEL 12—COLOR SYSTEM ANALYSIS

D. G. Fink, Chairman
A. G. Jensen, Vice Chairman
Scope: The function of Panel 12 shall include the detailed analysis and interpretation of such new technology as may be evolved in connection with the NTSC signal and the preparation of tutorial papers concerning such new technology.

PANEL 13—COLOR VIDEO STANDARDS

A. V. Loughren, Chairman
W. T. Wintringham, Vice Chairman
Scope: It will be the responsibility of this panel to provide recommended standards relating to the complete video signal. As such, it will include the determination of both colorimetric and electronic specifications. The purview of this committee will include the following:

1) Camera-taking characteristics.
2) Gamma characteristics.
3) Color carrier frequency and its phase relation with respect to horizontal synchronizing signals.
4) The color sequence to be used and whether or not it should be of oscillating type.
5) Bandwidths of monochrome and color signals.
6) Relative amplitudes of the monochrome signal and the color carrier.
7) Determination of the maximum system amplitude demands at critical colors to enable the determination of picture-to-synchronizing ratios.
8) Specification of radiated signal.

SUBCOMMITTEE #1—Gamma
R. D. Kell, Chairman

SUBCOMMITTEE #2—Receivers
W. E. Bradley, Chairman

SUBCOMMITTEE #3—Drafting of Standards
B. F. Tyson, Chairman

SUBCOMMITTEE #4—Special Task Group on Computation of Color Signal Parameters—No Chairman

SUBCOMMITTEE #5—Subcommittees to List the Reasons for the Motions Adopted by Panel 13
B. F. Tyson, Chairman

SUBCOMMITTEE #6—Ad Hoc Subcommittee on Review of Matters Pending Before Panel 13
A. V. Loughren, Chairman

SUBCOMMITTEE #7—Ceiling Performance
R. D. Thompson, Chairman

SUBCOMMITTEE #8—Visibility of Beatnote Between Sound and Color Subcarrier
G. H. Brown, Chairman

SUBCOMMITTEE #9—Chrominance Signal Specification
H. A. Samulon, Chairman

SUBCOMMITTEE #10—Ad Hoc Committee to Judge the Performance of Receivers on October 23, 1952
W. L. Brewer, Chairman

SUBCOMMITTEE #11—Choice of Axes
R. D. Kell, Chairman

SUBCOMMITTEE #12—Standardization of Set-Up in the NTSC Color Signal
B. F. Tyson, Chairman

SUBCOMMITTEE #13—Ad Hoc Subcommittee on Viewing of Compatibility Tests on November 19, 1952
A. G. Jensen, Chairman

SUBCOMMITTEE #14—Gamma Specifications
B. D. Loughlin, Chairman

PANEL 14—COLOR SYNCHRONIZING STANDARDS

D. E. Harnett, Chairman
R. N. Harmon, Vice Chairman
Scope: It will be the responsibility of this panel to provide recommended standards for color synchronizing signals and the interrelation with normal deflection synchronizing signals. This committee will also consider the interaction between the proposed color standards and the existing black and white standards in this regard.

SUBCOMMITTEE #1—Color Synchronizing Stability
B. D. Loughlin, Chairman

SUBCOMMITTEE #2—Effects of Side-Band Limiting on the Waveform of Color Synchronizing Signals
S. Doba, Chairman

SUBCOMMITTEE #3—Adequacy of Field Sensing Information
R. B. Dome, Chairman

SUBCOMMITTEE #4—TV Network Characteristics
R. N. Harmon, Chairman

SUBCOMMITTEE #5—Compatibility
D. E. Harnett, Chairman

SUBCOMMITTEE #6—Ultimate Performance
R. G. Clapp, Chairman

PANEL 15—RECEIVER COMPATIBILITY

Rinaldo DeCola, Chairman
W. O. Swinyard, Vice Chairman
Scope: It will be the responsibility of this panel to insure by actual observations during field tests that the proposals of the panels as executed will result in satisfactory compatible black-and-white pictures and sound when viewed by available black-and-white receivers including the effect on broadcasting coverage.

TASK GROUP—Chicago
B. S. Parmet, Chairman

TASK GROUP—Syracuse
W. J. Gruen, Chairman

TASK GROUP—Washington, D. C.
R. N. Harmon, Chairman

TASK GROUP—New York City
D. D. Israel, Chairman

TASK GROUP—Philadelphia
E. C. Freeland, Chairman
Scope: Conduct compatibility tests in accordance with procedures established by Chicago Sub-Committee on Test Procedures.

Sub-Committee on Test Procedures
W. O. Swinyard, Chairman

PANEL 16—FIELD TESTING

Knox McIlwain, Chairman
D. W. Pugsley, Vice Chairman
Scope: It will be the responsibility of this panel to insure by actual observations during field tests that the proposed standards will result in a signal which will satisfactorily operate color receivers and provide the public with service which, in color, is comparable in performance to that established by the monochrome standards.

COMMITTEE #4—
Color Receiver Committee
R. A. Mahler, Chairman

COMMITTEE #5—
Color Receiver Acceptance Characteristics Committee
W. F. Bailey, Chairman

COMMITTEE 6—
Signal Certification Committee
F.J. Bingley, Chairman

COMMITTEE #1—
Color Test Bulletin Committee
R. P. Wakeman, Chairman

COMMITTEE #2—
Equipment Availability Committee
D. W. Pugsley, Chairman

COMMITTEE #3—
Field Test Planning Committee
J. A. Hansen, Chairman

Chicago Task Force
John Rennick, Chairman

Ad Hoc Committee on Bilateral Interference Between Amateur Transmitters and Receivers and Receivers Receiving NTSC Color TV Signals
Earl I. Anderson, Chairman

Ad Hoc Committee on Susceptibility of Color TV Receivers to Interference
George Brown, Chairman

Ad Hoc Committee on Susceptibility of Color TV Receivers to Hum
Charles J. Hirsch, Chairman

Ad Hoc Committee on Color Blindness
M. W. Baldwin, Jr., Chairman

FCC Observers

PANEL 17—BROADCAST SYSTEM

R. E. Shelby, Chairman
J. M. Barstow, Vice Chairman
Scope: It will be the responsibility of this panel to insure by actual observation during field tests that the proposed standards will result in a signal which can be satisfactorily broadcast by present broadcast transmitters with only minor changes and can be transmitted from city to city by means of existing or presently contemplated inter-city program circuits. In addition, the panel will analyze the equipment required at the studio as well as the transmitter for the NTSC color signal as compared with the present black-and-white signal.

SUBCOMMITTEE ON STUDIO FACILITIES
R. J. Rockwell, Chairman

SUBCOMMITTEE ON NETWORK AND TRANSMISSION
H. C. Gronberg, Chairman

SUBCOMMITTEE ON TV TRANSMITTER FACILITIES
R. N. Harmon, Chairman

PANEL 18—CO-ORDINATION

D. B. Smith, Chairman
I. J. Kaar, Vice Chairman
Scope: The function of this panel will be liaison and co-ordination between the panels to reduce duplication of effort, and to resolve matters of scope and jurisdiction among the panels.

SUBCOMMITTEE ON DEMONSTRATIONS
D. B. Smith, Chairman
Scope: This is an Ad Hoc Committee set up to study and report to the Panel concerning technical phases of a possible demonstration of NTSC Standards to the FCC.

SUBCOMMITTEE ON REVIEWING FIELD TESTS
F. J. Bingley, Chairman
Scope: This subcommittee was set up for purpose of reviewing proposed field tests of the several NTSC panels from the point of view of being sure that all the technical information required by Commission, either directly or indirectly, is adequately handled.

PANEL 19—DEFINITIONS

Dr. R. M. Bowie, Chairman
M. W. Baldwin, Jr., Vice Chairman
Scope: It will be the responsibility of this panel to produce a glossary of terms and working definitions as used in color television and color generally as required in the formulation of color television standards.

SYMBOLS SUBCOMMITTEE
R. P. Burr, Chairman
Scope: "The Symbols Subcommittee is charged with the preparation of a set of working symbols with definitions for use in color television and color generally as required in the formulation of color television standards, giving due consideration to both the philosophy of symbol assignment and the existing symbols of the IRE Symbols Committee (IRE 21)."

CONSISTENCY SUBCOMMITTEE
R. W. Waggener, Chairman
Scope: "The assignment to the Subcommittee was to review from time to time the definitions of Panel 19 including the NTSC-approved definitions, to determine any inconsistencies appearing therein and at the discretion of this Subcommittee to bring the matters under question to the attention of Panel 19 for possible action."

NTSC Signal Specifications*

There is presented here the technical signal specifications formulated by the National Television System Committee and approved by the Federal Communications Commission on December 17, 1953 as the technical transmission standards for commercial color television broadcasting in the United States.—*The Editor*

I. General Specifications

A. Channel

The color television signal and its accompanying sound signal shall be transmitted within a 6 mc channel.

B. Picture Signal Frequency

The picture signal carrier, nominally 1.25 mc above the lower boundary of the channel, shall conform to the frequency assigned by the FCC for the particular station.

C. Polarization

The radiated signals shall be horizontally polarized.

D. Vestigial Sideband Transmission

Vestigial sideband transmission in accordance with Fig. 2 shall be employed.

E. Aspect Ratio

The aspect ratio of the scanned image shall be four units horizontally to three units vertically.

F. Scanning and Synchronization

1. The color picture signal shall correspond to the scanning of the image at uniform velocities from left to right and from top to bottom with 525 lines per frame interlaced 2:1.

2. The horizontal scanning frequency shall be 2/455 times the color subcarrier frequency; this corresponds nominally to 15,750 cycles per second (with an actual value of 15,734.264$\pm$0.047 cycles per second). The vertical scanning frequency is 2/525 times the horizontal scanning frequency: this corresponds nominally to 60 cycles per second (the actual value is 59.94 cycles per second).

3. The color television signal shall consist of color picture signals and synchronizing signals, transmitted successively and in different amplitude ranges except where the chrominance penetrates the synchronizing region, and the burst penetrates the picture region.

4. The horizontal, vertical, and color synchronizing signals shall be those specified in Fig. 1, as modified by vestigial sideband transmission specified in Fig. 2 and by the delay characteristic specified in III.B.

* Decimal classification: R583$\times$R020. Approved by Panel 13, July 8, 1953, and the NTSC, July 21, 1953. Reprinted from Appendix A of the NTSC petition to the FCC.

G. Out-of-Channel Radiation

The field strength measured at any frequency beyond the limits of the assigned channel shall be at least 60 db below the peak picture level.

II. Sound

A. Sound Signal Frequency

The frequency of the unmodulated sound carrier shall be 4.5 mc$\pm$1,000 cycles above the frequency actually in use for the picture carrier.

B. Sound Signal Characteristics

The sound transmission shall be by frequency modulation, with maximum deviation of $\pm$25 kc, and with pre-emphasis in accordance with a 75 μsec time constant.

C. Power Ratio

The effective radiated power of the aural-signal transmitter shall be not less than 50 per cent nor more than 70 per cent of the peak power of the visual signal transmitter.

III. The Complete Color Picture Signal

A. General Specifications

The color picture signal shall correspond to a luminance (brightness) component transmitted as amplitude modulation of the picture carrier and a simultaneous pair of chrominance (coloring) components transmitted as the amplitude modulation sidebands of a pair of suppressed subcarriers in quadrature having the common frequency relative to the picture carrier of $+3.579545$ mc ±0.0003 per cent with a maximum rate of change not to exceed 1/10 cycle per sec per sec.

B. Delay Specification

A sine wave, introduced at those terminals of the transmitter which are normally fed the color picture signal, shall produce a radiated signal having an envelope delay, relative to the average envelope delay between 0.05 and 0.20 mc, of zero μsecs up to a frequency of 3.0 mc; and then linearly decreasing to 4.18 mc so as to be equal to -0.17 μsecs at 3.58 mc. The tolerance on the envelope delay shall be $\pm$0.05 μsecs at 3.58 mc. The tolerance shall increase linearly to $\pm$0.1 μsec, down to

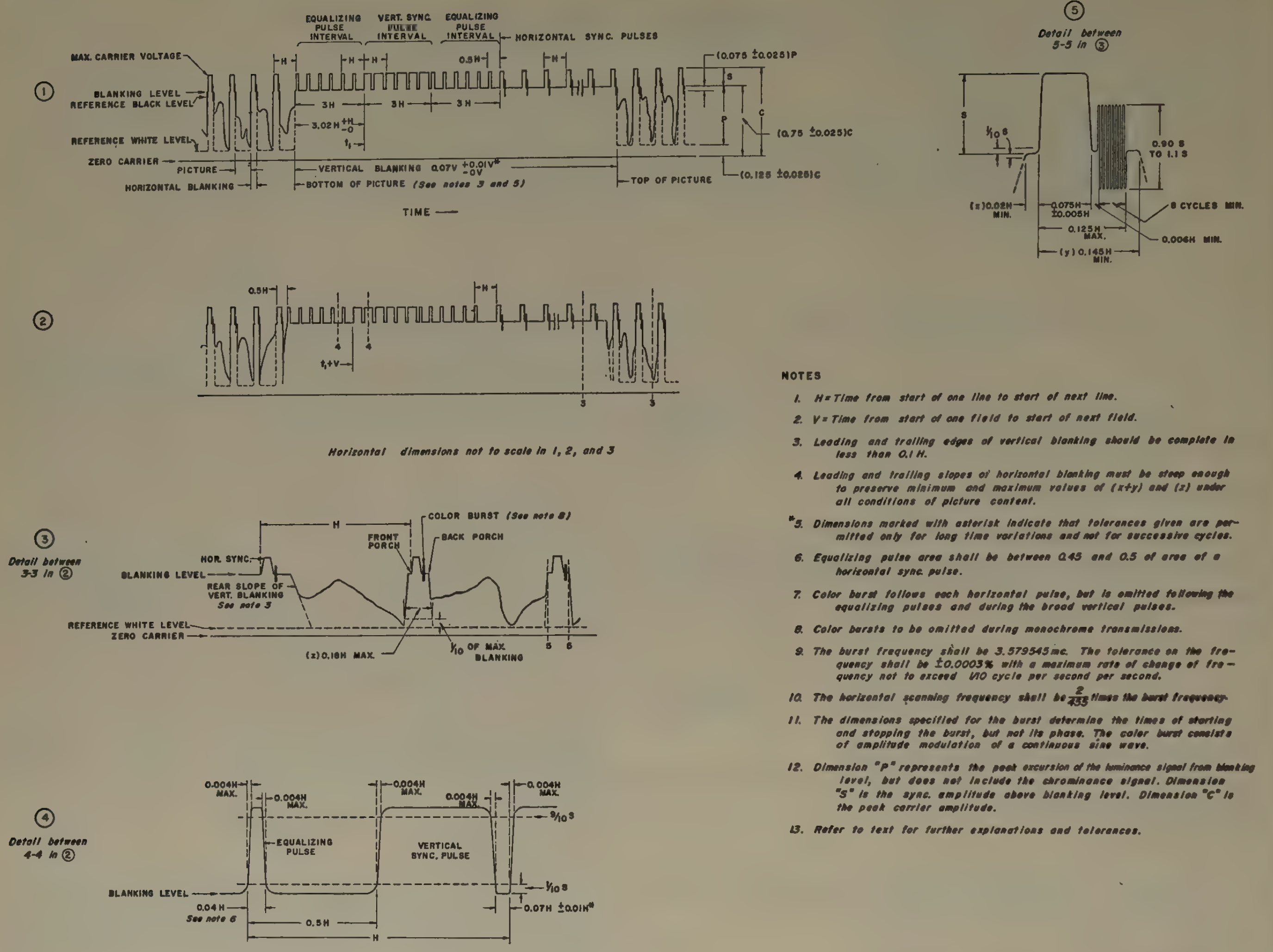


Fig. 1

2.1 mc, and remain at ± 0.1 μsec down to 0.2 mc.[1] The tolerance shall also increase linearly to ± 0.1 μsec at 4.18 mc.

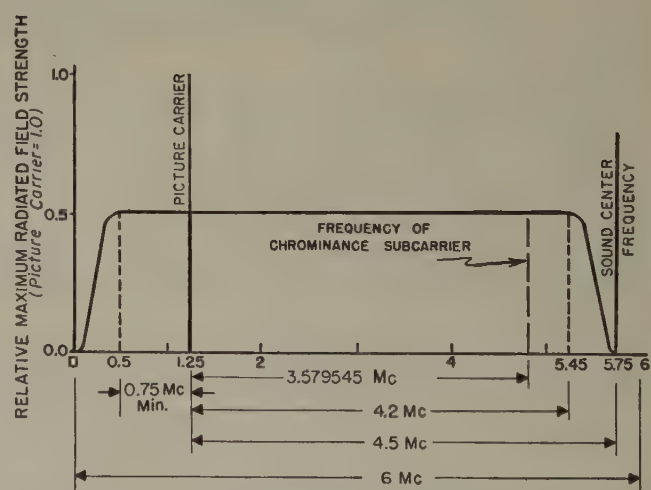
C. The Luminance Component

1. An increase in initial light intensity shall correspond to a decrease in the amplitude of the carrier envelope (negative modulation).

2. The blanking level shall be at (75 ± 2.5) per cent of the peak amplitude of the carrier envelope. The reference white (luminance) level shall be (12.5 ± 2.5) per cent of the peak carrier amplitude. The reference black level shall be separated from the blanking level by the setup interval, which shall be (7.5 ± 2.5) per cent of the video range from the blanking level to the reference white level.

3. The over-all attenuation versus frequency of the luminance signal shall not exceed the value specified by the FCC for black-and-white transmission.

[1] Tolerances for the interval of 0.0 to 0.2 mc should not be specified in the present state of the art.



Note: Not drawn to scale

Fig. 2

D. Equation of Complete Color Signal

1. The color picture signal has the following composition:

$$E_M = E_Y' + \left\{ E_Q' \sin(\omega t + 33^\circ) + E_I' \cos(\omega t + 33^\circ) \right\}$$

where

$$E_Q' = 0.41(E_B' - E_Y') + 0.48\,(E_R' - E_Y')$$
$$E_I' = -\,0.27(E_B' - E_Y') + 0.74\,(E_R' - E_Y')$$
$$E_Y' = 0.30E_R' + 0.59E_G' + 0.11\,E_B'.$$

The phase reference in the above equation is the phase of the (color burst +180°), as shown in Fig. 3. The burst corresponds to amplitude modulation of a continuous sine wave.

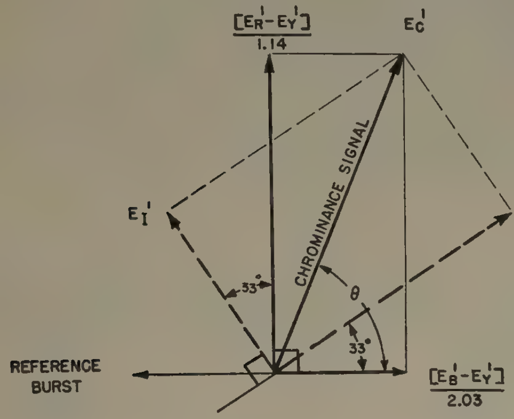


Fig. 3

Notes: For color-difference frequencies below 500 kc, the signal can be represented by

$$E_M = E_Y' + \left\{\frac{1}{1.14}\left[\frac{1}{1.78}\,(E_B' - E_Y')\sin \omega t + (E_R' - E_Y')\cos \omega t\right]\right\}.$$

In these expressions the symbols have the following significance:

E_M is the total video voltage, corresponding to the scanning of a particular picture element, applied to the modulator of the picture transmitter.

E_Y' is the gamma-corrected voltage of the monochrome (black-and-white) portion of the color picture signal, corresponding to the given picture element.[2]

E_R', E_G', and E_B' are the gamma-corrected voltages corresponding to red, green, and blue signals during the scanning of the given picture element.

The gamma corrected voltages E_R', E_G', and E_B' are suitable for a color picture tube having primary colors with the following chromaticities in the CIE system of specification:

	x	y
Red (R)	0.67	0.33
Green (G)	0.21	0.71
Blue (B)	0.14	0.08

[2] Forming of the high frequency portion of the monochrome signal in a different manner is permissible and may in fact be desirable in order to improve the sharpness on saturated colors.

and having a transfer gradient (gamma exponent) of 2.2[3] associated with each primary color. The voltages E_R', E_G', and E_B' may be respectively of the form $E_R^{1/\gamma}$, $E_G^{1/\gamma}$, and $E_B^{1/\gamma}$ although other forms may be used with advances in the state of the art.

E_Q' and E_I' are the amplitudes of two orthogonal components of the chrominance signal corresponding respectively to narrow-band and wide-band axes, as specified in paragraph *D*.

The angular frequency ω is 2π times the frequency of the chrominance subcarrier.

The portion of each expression between brackets represents the chrominance subcarrier signal which carries the chrominance information.

1. The chrominance signal is so proportioned that it vanishes for the chromacity of CIE illuminant *C* ($x=0.310$, $y=0.316$).

2. E_Y', E_Q', E_I' and the components of these signals shall match each other in time to 0.05 μsecs.

3. A sine wave of 3.58 mc introduced at those terminals of the transmitter which are normally fed the color picture signal shall produce a radiated signal having an amplitude (as measured with a diode on the RF transmission line supplying power to the antenna) which is down (6±2) db with respect to a radiated signal produced by a sine wave of 200 kc. In addition, the amplitude of the radiated signal shall not vary by more than ±2 db between the modulating frequencies of 2.1 and 4.18 mc.

4. The equivalent bandwidths assigned prior to modulation to the color-difference signals E_Q' and E_I' are given by Table I.

TABLE I

Q-channel bandwidth
at 400 kc less than 2 db down
at 500 kc less than 6 db down
at 600 kc at least 6 db down
I-channel bandwidth
at 1.3 less than 2 db down
at 3.6 mc at least 20 db down

5. The angles of the subcarrier measured with respect to the burst phase, when reproducing saturated primaries and their complements at 75 per cent of full amplitude, shall be within ±10° and their amplitudes shall be within ±20 per cent of the values specified above. The ratios of the measured amplitudes of the subcarrier to the luminance signal for the same saturated primaries and their complements shall fall between the limits of 0.8 and 1.2 of the values specified for their ratios. Closer tolerances may prove to be practicable and desirable with advance in the art.

[3] At the present state of the art it is considered inadvisable to set a tolerance on the value of gamma and correspondingly this portion of the specification will not be enforced.

NTSC Color Television Field Test*

RINALDO DECOLA†, SENIOR MEMBER, IRE, ROBERT E. SHELBY‡, FELLOW, IRE
KNOX McILWAIN§, FELLOW, IRE

Any proposal, for general standardization and Governmental acceptance, of signal specifications for a new and complex form of mass communication is a most serious project. Such specifications must minimize deterioration of existing services. They must offer an excellent and early new service of the proposed type. They must be sufficiently definite to set reasonably high and immediate performance standards. And yet they must be sufficiently broad and flexible to offer possibilities of major future service improvements lying within the assigned specificational framework. Such difficult, and seemingly almost self-contradictory requirements, may well tax the skill of even the most experienced and ingenious engineers.

It is therefore encouraging to find, as shown in the following unified paper, that elaborate field tests show that there was good reason to believe that the National Television System Committee had indeed successfully carried out its task of setting signal specifications which, when critically tested, met all appropriate technical and service requirements.

Readers of these PROCEEDINGS are indebted to the three NTSC Panel Chairmen who have prepared the following paper especially for this issue, thus substantially adding to its completeness as a color-television symposium and to its technical and industrial values.—*The Administrative Editor.*

***Summary*—When a signal specification is intended for a public broadcast service, it is vitally necessary to make sure in advance that:**

1. It can be fitted into the spectrum (in this instance this means that it be compatible with the present monochrome system).

2. It will give satisfactory service.

3. It can be sent over the networks.

Field tests, as opposed to laboratory measurements, with five transmitters and receivers from a number of manufacturers were made to test the NTSC signal specification. While difficulties were found in the field with a number of the earlier proposals, the final signal proposed triumphantly passed all tests and was recommended to the Federal Communications Commission for standardization and authorization of commercial broadcasting.

INTRODUCTION

THE SIGNAL specification for a color television system to be discussed in this paper was designed by the National Television System Committee to be used for a broadcast transmission service to the public. Once a system based on it is installed and operating, and equipment for it is merchandised in large quantity, it becomes extremely difficult, if not impossible, to change it. Changes in the transmitters can be made only if they do not degrade the performance of receivers already in the hands of the public. Since these receivers were designed specifically to receive the previously authorized transmission, the field of possible changes of the standards is strictly limited.

As a consequence of this, it follows that every effort must be made in advance of installation to determine whether the signal specification is in fact the best that can be devised to do the job. In particular it must be shown that:

1. A system based on the proposed signal specification can be introduced and extended throughout the country without undue disturbance to other services now in operation. In this particular instance this includes the present monochrome television service.
2. The signal specification is adequate to give satisfactory color pictures in the home of a quality comparable to the present monochrome system.
3. The signals created under the specification must be such that they can be transmitted over a practical network system without undue degradation and must be such that they can be radiated from practical transmitters.
4. While it is necessary that equipment exist to demonstrate the fact that the signal specification is the best that can be devised, it does not follow that the standards should be limited by present equipment. It is very desirable that the standards leave as much room as possible for the improvement and development of superior equipment.

Each of these requirements has many ramifications. The signal specification must be capable of giving good pictures under favorable conditions, but it must also be capable of providing reasonably good pictures even when the conditions are less than optimum. It must not be too susceptible to degradation by the various noises and interferences which it will encounter, must not be too subject to deterioration by multipath transmissions, and above all must not of itself create a situation in which it is incapable of operating successfully as a universal broadcasting service.

On the other side of the coin, the system to be installed must fit into the present allocation plan. Furthermore, it must not create undue interference to other currently operating services, either by its normal radiations, nor by spurious radiations of either one or more of its components, or by harmonics thereof.

These determinations can in many instances be made in the laboratory under controlled conditions, and in-

* Decimal classification: R583.7. Original manuscript received by the Institute, September 22, 1953.
† Admiral Corp., Chicago, Ill.
‡ National Broadcasting Co., New York, N. Y.
§ Hazeltine Corp., Little Neck, L. I., N. Y.

deed this is the best way to sort out the inferior proposals and determine which signal has the best chance of success. However, it is impossible to anticipate all of the difficulties which will be encountered when a new service such as color television is introduced into a crowded spectrum. To be completely sure that the specification is good enough—but not too restrictive—the final tests must be made in the field. They must be made at a variety of locations, where the observer takes conditions as he finds them and cannot adjust them to suit his requirements. They must be made with different transmitters, different receiving sites, and with receivers of various design and manufacture. Only in this way can one be reasonably sure that all of the potential difficulties have been experienced. It is for these reasons that comprehensive field tests of the NTSC proposed signal specification were made.

The Field Test Panels

In the organization of the National Television System Committee for the development of color standards, nine Panels were set up, and the work of the Committee was divided among them. Six of these Panels will be of importance in the discussion of the field tests and are identified as:

Panel 13—Color Video Standards
Panel 14—Color Synchronizing Standards
Panel 15—Receiver Compatibility
Panel 16—Field Testing
Panel 17—Broadcast System
Panel 18—Coordination.

The first two of these Panels were charged with synthesizing a satisfactory signal. It was expected that they would conduct enough laboratory tests to assure themselves of the various steps required and to guide them to the best compromises. It was their function to evolve a set of signal specifications, with tolerances, which was theoretically best suited to fulfill the outlined requirements.

The next three of these Panels are the so-called field test Panels, named so because much of their work must be done in the public area, outside of the laboratory, and largely under uncontrolled conditions. It was the assigned function of these groups to determine that Panels 13 and 14 had in fact specified a signal which would produce satisfactory color pictures under practical working conditions and would not cause too much disturbance either to itself or to other services when introduced on a large-scale basis.

Specifically, Panel 15 was charged with the following task: "It will be the responsibility of this panel to insure by actual observation during field tests that the proposals of the panels as executed will result in satisfactory compatible black and white pictures and sound when viewed by available black and white receivers including the effect on broadcast coverage."

The duties of Panel 16 were stated thus: "It will be the responsibility of this panel to insure by actual observations during field tests that the proposed standards will result in a signal which will satisfactorily operate color receivers and provide the public with service which, in color, is comparable in performance to that established by the monochrome standards."

For Panel 17 the corresponding statement was: "It will be the responsibility of this panel to insure by actual observations during field tests that the proposed standards will result in a signal which can be satisfactorily broadcast by present broadcast transmitters with only minor changes and can be transmitted from city to city by means of existing or presently contemplated inter-city program circuits. In addition, the panel will analyze the equipment required at the studio as well as the transmitter for the NTSC color signal as compared with the present black and white signal."

In brief these three Panels covered compatibility with the present monochrome system, adequacy of the signal specification to give good color pictures, and insurance that equipment requirements were not unreasonable.

Organization of the Field Tests

At the start of the NTSC work there was the problem of deciding just what a field test comprised. A subcommittee of the Coordination Panel (#18) was formed to determine this. This committee reviewed every document it could find which had any information or statement of requirements for field tests, including:

1. Standards of Good Engineering Practice Concerning Television Broadcast Stations, dated December 19, 1945.
2. FCC Public Notice No. 49-948 (FCC Mimeo No. 37460), dated July 11, 1949.
3. Report of RMA Color Television Committee No. 4, dated October 19, 1949.
4. FCC Public Notice No. 49-1547, issued November 22, 1949, "Notice Concerning Field Test Programs and Further Testimony."
5. FCC Public Notice No. 50-563, released May 10, 1950, "Notice Concerning Proposed Findings and Conclusions."
6. Report of the Advisory Committee on Color Television to the Committee on Interstate and Foreign Commerce, United States Senate, Document No. 197, dated July 14, 1950.
7. FCC Public Notice No. 50-1064, September 1, 1950 (often referred to as the First Color Television Report of FCC).
8. FCC Public Notice No. 50-1224, October 10, 1950 (often referred to as the Second Color Television Report of FCC).
9. Report of the Ad Hoc Committee of the NTSC, April 19, 1951 (Document NTSC-AHCT-75).
10. FCC Document No. 51–592, Public Notice 65008, dated June 11, 1951.

A list of requirements was drawn up with cross references to descriptions of the different tests desired. These requirements were then allocated to the several Panels, in so far as possible, who were notified of the tests which would be their responsibility.

These allocations defined in detail for each of the field test Panels what tests must be made, and in so far as possible the reasons for the tests and statement of the results required. The Panel testing was geared to cover these requirements as a minimum. In some cases additional tests were added.

Where it was decided that particular tests were not within the scope of NTSC, as in the case of all public reaction tests, the pertinent group (broadcasters, common carriers, equipment manufacturers, or television receiver manufacturers) was advised of the situation. It was hoped that these groups would make the appropriate tests and be prepared to offer evidence that the signal specification was satisfactory on all counts.

Compatibility[1]

The scope of Panel 15, as outlined, and cited in the introduction to this paper reads, "It will be the responsibility of this panel to insure by actual observation during field tests that the proposals of the panels as executed will result in satisfactory compatible black and white pictures and sound when viewed by available black and white receivers including the effect on broadcast coverage."

Panel 19, which was given responsibility for the definition of technical terms, later also defined compatibility as, "The nature of the color television systems which permit substantially normal monochrome reception of the transmission by typical unaltered monochrome receivers designed for standard monochrome."

Panel 15 interpreted the word "unaltered" as meaning: "Receivers are to be considered 'unaltered' if only receiver controls normally provided are readjusted. Possible adjustments would be fine-tuning, brightness and contrast." In actual field tests it later evolved that only the fine-tuning control in some cases required readjustment.

Panel Organization

Panel 15 was organized in July of 1951. Its membership comprised practicing engineers employed by electronic firms for the design of television receivers, television broadcast engineers, engineers in communications equipment design, television research engineers, television transmitter design engineers, and editorial writers for technical publications. Also, acting as observers on field tests but not members of Panel 15 were members of the teaching profession, television service engineers and consulting engineers. During the first meeting the following procedures and plans were formulated:

[1] This section was written by R. DeCola, Chairman of Panel 15.

1. To set up task groups on field testing in New York City, Philadelphia, Washington, Syracuse, and Chicago.
2. That these task groups would conduct shake-down tests on color signals to determine compatibility.
3. When preliminary shake-down tests indicated that compatibility was reasonably assured, official field tests, attended by Panel 15 members, would be conducted at the various test cities to evaluate the receivers for compatibility.
4. Organize a sub-committee on field test procedures to formulate rules and definitions and prepare field test report forms, in line with the requirements laid down by Panel 18. (See Introduction.)

Types of Monochrome Receivers

At the time of the first meeting (July, 1951) there were somewhat over 10,000,000 television receivers in the hands of the public. This represented the manufacturing efforts of over 80 different producers over a period of some six years. During this period, each manufacturer had produced an appreciable variety of basic chassis designs. Furthermore, manufacturing continued at a yearly rate of approximately 6,000,000 additional receivers each year.

At the conclusion of the Panel 15 field tests early in June, 1953, something like 23,000,000 receivers were in the hands of the public.

Very early in its existence Panel 15 realized that to evaluate properly the compatibility of publicly owned receivers, the basic circuitry of these receivers would have to be analyzed and classified, so that a reasonably small number of receivers would yield a high order of reliability in the over-all evaluation of compatibility.

In October, 1951, the sub-committee on Field Test Procedure enumerated the factors to be considered in receiver selection to encompass all receivers in existence. These were:

I. *Horizontal AFC (Automatic Frequency Control)*
   1. None (direct sync)
   2. Pulse on sine wave
   3. Pulse on sawtooth
   4. Pulse width

II. *Horizontal Oscillator*
   1. Sine Wave
   2. Blocking
   3. Multi-vibrator
   4. Stabilized multi-vibrator

III. *AGC (Automatic Gain Control)*
   1. No AGC
   2. Simple
   3. Gated
   4. Amplified

IV. *Intermediate Frequency*
   1. 21 mc
   2. 41 mc

V. *Type of Sound Take-off*
  1. Intercarrier
    (a) Type sound detector
  2. Split-sound take-off
    (a) Type sound detector

VI. *DC Restoration*
  1. No DC restoration
  2. DC restoration
  3. DC coupled.

This same subcommittee obtained 12 television receivers which represented collectively the circuit differences indicated above. Careful laboratory measurements were made on all these receivers in order that operational peculiarities which might arise during unofficial compatibility tests could be properly appraised.

History of the Field Tests

On November 26, 1951, NTSC proposed a color signal specification for use in field testing. The important factors in this specification which concerned Panel 15 were the following:

1. The duration of the horizontal synchronizing pulses reduced to 0.06 H from 0.08 H standard for monochrome transmission.
2. The inclusion of a color burst signal on a pedestal located on the back porch of the horizontal pedestal.
3. The color sub-carrier of 3.898125 mc.
4. CPA (color phase alternation). This feature later was discontinued as part of the color signal specification, but has no bearing on compatibility.

During February, 1952, the Chicago Field Test Task Group, using closed circuit color signals and also radiated color signals from the experimental Zenith transmitter, ran preliminary shakedown tests on this NTSC proposed signal, using the 12 receivers mentioned.

These tests indicated that while some receivers responded well to the color signal, others showed very definite synchronization peculiarities. Of the receivers showing synchronization difficulties, some were affected by the reduced horizontal synchronizing pulse and not by the burst pedestal. Other sets showed vulnerability to the burst pedestal but produced no reaction to the reduced width of the horizontal synchronizing pulses.

Also, depending upon the bandwidth of the receiver, difficulty was experienced due to the beat between the color subcarrier and the sound carrier producing a 610 kc interfering pattern.

To varying extents these difficulties were also confirmed by the Syracuse and Philadelphia Task Groups.

Panels 13 and 14 on signal specifications during the course of their own work, and from communications with Panel 15, became aware of the difficulties which Panel 15 was encountering and set up subcommittees within their own panels to investigate these difficulties.

In January, 1953, NTSC approved for field testing the modified signal specifications from Panels 13 and 14. These modifications as they affected Panel 15 were:

1. Retain the horizontal pulse width at 0.08 H as for monochrome.
2. Delete the pedestal from the color subcarrier synchronizing burst.
3. Modify the frequency of the color subcarrier so as to obtain an interleaving (or frequency interlacing) effect in the beat action between the color subcarrier and the sound carrier, thus reducing the beat visibility.

During the latter part of April, 1953, shakedown tests were conducted by the Chicago and Philadelphia Task Groups, using the signals modified as indicated above. The results of these tests were very encouraging and indicated that a high order of compatibility existed.

Starting on May 14, and concluding on June 2, 1953, four official field tests were conducted. Two of these meetings were held in Chicago and one each in Jersey City and Philadelphia.

At each of these field tests, the task group chairman explained to Panel 15 members and observers the purpose of the test and the procedure to be used in scoring receivers. At each site the transmitter alternated between a monochrome signal and a color signal at approximately 10 second intervals in order to allow observation to be made. For this purpose, standard Kodachrome test slides supplied by Eastman Kodak Company, in accordance with proposals of NTSC Panel 11, were used.

A reproduction of the "Detailed Field Test Report" form used by each observer is shown in Fig. 1. Each observer had as many of these forms as there were receivers. Receivers were then scored on each of the eight tests indicated. Also, each test was scored four separate times, one each for slide groups A, B, C and D shown on Fig. 1, following page. No live tests were conducted.

Scoring Technique

The scoring was comparative, based on the monochrome signal as a standard. Two scales were required for scoring on this basis. They are shown below.

TABLE I

Scale 1		Scale 2
Degradation not perceptible	1	Excellent
Just perceptible	2	Good
Definitely perceptible but not objectionable	3	Passable
Somewhat objectionable	4	Not quite passable
Definitely objectionable	5	Poor
Not usable	6	Not usable

Scale 2 was used to score in the blocks under the "Monochrome Transmission" columns, and Scale 1 to score in the blocks under the "Color Transmission."

Thus, if during the monochrome transmission the observer judged the picture to be "passable," he would score 3 (Scale 2) under the appropriate monochrome

Revised 4-22-53

PANEL 15—COMPATIBILITY
NATIONAL TELEVISION SYSTEM COMMITTEE
DETAILED FIELD TEST REPORT

Field Test No. ________

Make ________ Model ________ Serial No. ________

Pic. Tube Size ______ in. Viewing Distance ______ ×pic. height. Room Illumination ________

Test Location ________ Distance to Xmtr. ______ mi. Signal Strength ______ uv at inp. term

Channel ______ Type Antenna ________ Height Above Ground ______ ft.

	Resolution	*Black and White*	*Black and Green*
Test 1.	Horizontal	______ lines	______ lines
	Vertical	______ lines	______ lines

		Color Transmission*					Monochrome Transmission					
	Slide Group	A	B	C	D		A	B	C	D		
Test	Slide Number					Live					Live	Notes
2. Over-all Picture Quality												
3. Flicker												
4. Brightness												
5. Contrast												
6. Picture Texture												
7. Adequacy of Sync												
8. Sound Quality												

* Comparative ratings based on the monochrome signal as a standard.

Observer's Signature ________

Company Affiliation ________

Title ________

Date ________

See Instruction Sheet for scoring techniques.

Fig. 1

column. Viewing the same slide during color transmission he judged the deterioration as "just perceptible" he would score 2 (Scale 1) under the appropriate color column.

The Subcommittee on Test Procedure described the tests in Fig. 1 as follows:

Test 1—Resolution

To compare the brightness resolution which can be obtained using the NTSC proposed signal in conjunction with monochrome receivers with that obtainable on a complete monochrome system.

Test 2—Over-all Picture Quality

Is a general qualitative analysis of the picture in order to determine whether there are any defections of unusual characteristics in the receiver's operation which may affect the results of the more detailed tests to follow. For instance, excessive noise in the picture may make some observations such as for picture texture, meaningless.

Test 3—Flicker

To determine what degree of flicker, if any, is observable on monochrome receivers when receiving signals transmitted in conformance with NTSC proposed standards.

Test 4—Brightness

To determine that the NTSC proposed standards provide for a signal of adequate brightness as compared with present standard monochrome transmission signals.

Test 5—Contrast

To determine that the NTSC proposed standards provide for a signal of adequate contrast range without degradation of half tones, as compared with present monochrome transmission signals.

Test 6—Picture Texture

To determine by observation of monochrome receiver pictures, derived from transmission conforming to the NTSC proposed standards, whether or not the reproduced picture contains any noticeable or objectionable texture such as dot structure, dot crawl, moiré, or any other beat pattern. An observation shall also be made to determine whether the horizontal retrace lines are visible.

Test 7—Adequacy of Synchronizing

To determine the adequacy of deflection synchronizing information in the proposed NTSC signal and to determine the effect, if any, of the addition of color synchronizing information in the color signal on the deflection synchronizing circuits.

Test 8—Sound Quality

To determine the effect of the addition of chroma information on the sound performance of monochrome receivers when receiving color signals conforming to NTSC proposed standards.

Results of Field Tests

Table II shows the rating totals for each field test and also the rating totals for all field tests. These results were obtained from Fig. 1, tests 2 through 8, as filled out for each set by each observer.

TABLE II
Summary of Panel 15 NTSC Field Test Results

	Observations Versus Ratings, Tests 2 to 8							Miscellaneous Data				
Field Test	Ratings							Number of Sets	Number of Observers	Field Strength	Missing Observations	Calculated No. of Observations
	1	2	3	4	5	6	Totals					
Chicago 1	3698	366	94	22	8	0	(a) 4188	16	(f) 10	3 mv	292	(d) 4480
Chicago 2	3542	0	0	0	0	0	3542	(e) 13	(b) 10	100 uv	70	3612
New York	9744	1086	169	6	0	0	11005	23	(c) 18	9 mv	503	11508
Philadelphia	4078	836	227	(h) 172	63	0	5376	16	12	0.1 v	0	5376
Totals	21062	2288	490	200	71	0	24111	(g) 68	50		865	24976
Per cent	87.4	9.5	2.0	0.8	0.3	0	100					

NOTES

(a) Actual observations made
(b) Nine observers for set #9
(c) Seventeen observers for sets #16, #20 and #21
(d) Sets×observers×tests (7)×slides (4)
(e) These sets were also used in Chicago #1 test
(f) Some observers participated in all field tests
(g) Fifty-five different sets were used
(h) Most of the low ratings were scored against split-sound sets

Table III shows the average recorded resolution for each field test and also the average resolution for all field tests. These results were obtained from Fig. 1, test 1. A loss in both horizontal and vertical resolution is indicated for color transmissions on all field tests.

TABLE III
RESULTS OF TEST 1 RESOLUTION

Field Test	Black and White		Black and Green		Reduction %
	Lines	%	Lines	%	
Chicago 1 (a)					
Hor.	277	100	250	90	10
Vert.	318	100	300	94	6
New York					
Hor.	314	100	297	94.5	5.5
Vert.	436	100	423	97	3.0
Philadelphia					
Hor.	264	100	237	88.8	11.2
Vert.	377	100	350	92.9	7.1
Average (b)					
Hor.	294	100	271	92	8.0
Vert.	397	100	380	96	4.0

Notes: (a) Chicago test #2, fringe area, no resolution observations possible due to noise.
(b) Weighted average.

The first Chicago field test designated "Chicago 1" gave the results shown in Table II; this test used the 12 receivers mentioned earlier in this report and in addition used four more current receivers.

The Chicago 2 field test generally used the same receivers, but the signal input to the receivers was reduced to 100 microvolts. At this signal level, as contrasted to the previous Chicago 1 test run at 9,000 microvolts, no difference could be scored between the monochrome and color transmissions. This was due to the inherent receiver noise completely masking any deleterious effects contributed by the color information.

The New York field tests results showed the best overall rating. This was no doubt due to the receivers being current production models and all of the intercarrier type. Also the signal input to the receivers was only moderately strong.

The Philadelphia test involved receiver input levels of 100,000 microvolts, and also older types of receiver designs. Four of the sixteen receivers were of the "split-sound" type. The field test results for the Philadelphia test indicated the poorest results, as can be seen in Table II.

The ratings of "5" shown on Table II were all based on the visibility of the color subcarrier. The receivers which exhibited this effect were all of the "split-sound" type, and the result was to a certain extent occasioned by the inflexible fine-tuning requirements of this type of receiver. In the intercarrier receivers it was possible to retune the receivers in all cases so that the color subcarrier's visibility was almost indiscernible.

Nevertheless, the total of all ratings shown in Table II indicated a rather high degree of compatibility, for out of a total of 24,111 observations, 21,062 (87.4 per cent) were rated as "1" or "not perceptible," and only 71 observations (0.3 per cent) were rated "5" or "definitely objectionable."

Table IV shows separately the ratings obtained on five split-sound receivers. Four of these receivers were used in the Philadelphia field test, and the fifth one was used in the Chicago field test. It will be noted from Table IV that receivers number 11 and 15 contributed approximately 90 per cent of all the "5" ratings.

In tests subsequent to the Philadelphia field test it was found that with the insertion of approximately 14 db attenuation at the receiver input terminals the color subcarrier visibility was reduced to a practically invisible point. This attenuation was inserted at the input terminals of receivers 11 and 15. Because of the high input signal to these receivers, it was felt that the mixer tubes caused intermodulation of the various carriers resulting in a condition which could not be remedied by the fine tuning control, but required attenuation of the input signal for corrective action. That beat visibility is not necessarily associated with all split-sound receivers is evident from Table IV where two of the receivers did not rate anything lower than "4," or "somewhat objectionable."

TABLE IV
SUMMARY OF PANEL 15 NTSC
FIELD TEST RESULTS OF FIVE "SPLIT-SOUND" RECEIVERS

Location and Receiver #	Rating						Total All Ratings
	1	2	3	4	5	6	
PHILADELPHIA Receiver #5	206	55	44	31	0	0	336
PHILADELPHIA Receiver #11	227	13	4	56	36	0	336
PHILADELPHIA Receiver #8	199	105	32	0	0	0	336
PHILADELPHIA Receiver #15	224	26	18	41	27	0	336
CHICAGO Receiver #10	193	13	39	16	6	0	267
Totals	1049	212	137	144	69	0	1611

A test was also conducted to observe a re-run of rather elaborate interference tests previously conducted by Dr. G. L. Fredendall[2] of RCA, Princeton. The results of this test were summarized as follows:

1. Co-channel Interference: Color and monochrome are substantially equally susceptible.

[2] G. L. Fredendall, "A comparison of monochrome and color television with reference to susceptibility to various types of interference," included in Panel 16, NTSC, report to the FCC; Aug. 1953. *RCA Review*, p. 341; September, 1953.

2. Lower Adjacent Channel Interference: Color and monochrome are substantially equally susceptible. Lower adjacent sound signal is predominant cause of interference. Receiver attenuation in lower adjacent channel is a determining factor.
3. Upper Adjacent Channel Inteference: Color is somewhat more susceptible than monochrome (6–8 db) in the present tests. Transmitter attenuation in the adjacent channel is the determining factor, provided that receiver attenuation for the adjacent picture carrier is sufficient. However, the ratio desired carrier to interfering carrier of −16 db for tolerable interference is well above the ratio of 0 db set by the FCC.
4. Random Noise: Color is somewhat more susceptible to random noise to the extent of only about 1 db.
5. Sine Wave Interference: Color is more susceptible to sine wave interference in the vicinity of the color subcarrier.
6. Multipath: Color is somewhat more susceptible to the extent of only about 1–2 db.
7. Impulse Noise: Color and monochrome are substantially equally susceptible.

Conclusions

The conclusion of Panel 15 was that the color signal specification of NTSC is a compatible color signal capable of giving practically unaltered performance, as compared to monochrome transmission on all existing monochrome receivers.

Intercarrier television receivers indicate better compatibility than split-sound television receivers. Split-sound receivers, because of the inflexible nature of the fine-tuning adjustment, show some deterioration of picture quality due to the beat between the color subcarrier and the sound carrier.

Color Receivers[3]

The field tests performed by Panel 16 break down naturally into three broad divisions:

1. The first of these comprises those tests in which actual numerical values can be derived, such as resolution, brightness, and contrast ratio.
2. The second group includes tests intended to show that the signal specification is capable of making pleasing pictures. Typical qualities are registration, color fidelity, continuity of motion, and so forth.
3. The third set of tests covers the susceptibility and nuisance factors of the system for various forms of interference and noise. Can the proposed color television system operate in the crowded spectrum without undue degradation to itself or to other services?

[3] This section was written by K. McIlwain, Chairman of Panel 16.

The first and second of these sets of tests have in common the requirement that they should both be made on a considerable number of transmitters and receivers of various design and manufacture to help to determine the difficulty of constructing practical apparatus to operate with the proposed signal specification. Since the tests of the first group require the reading of a number from a test chart, or reading of a meter, so that little subjective judgment is necessary, a reliable reading should be obtained from the average of some three or four observers. The second group, however, depends purely on subjective evaluations and so requires judgments by a larger group of trained observers. Only such expressions as good, bad, and indifferent could be used, so that a considerable part of the problem was evolving a suitable scoring technique to which all could agree. The solution was the recording of judgments by the numerical scales described under Scoring Technique, above, and shown in Table I. From these judgments statistical distribution curves have been plotted to give a convincing picture of the worth of the system for a particular characteristic. A list of various characteristics for which the sets were judged is given in the left-hand column of Fig. 2. These cover all subjective characteristics that were assigned to the Panel by Panel 18.

Since assembling a group of receivers at one location at a particular time presented some difficulties of scheduling and shipping, it was decided to run these first two groups of tests together, with the whole Panel present and with as many receivers available as was possible.

The third set of tests required quite different conditions of observation. This set covered such measurements as susceptibility of the system to co-channel and adjacent-channel interference, to random and impulse noise, to sine-wave interference, and to the effect of multipath (echoes), and hum. On the other side of the fence, a series of tests was run with the American Radio Relay League to determine the bilateral interference effects between color television receivers and amateur installations in the 80-, 40-, and 20-meter bands. The most meaningful measurements for all of these tests in the third group seemed to be a comparison with the performance of the present monochrome system to obtain relative rather than absolute values. Thus, these tests are a combination of measurement and judgment; the observer must measure (in db) how much worse the behavior of the color system is than that of the black-and-white system or vice versa. In general, this type of test must be made with only one observer at a time—since the observer must be able to adjust an attenuator until he believes a proper balance has been achieved between the two transmissions. For this reason these tests were carried out by small groups, frequently consisting of but one operator and one observer working at a time. In all cases the techniques used were made known to, and approved by, the Panel and the results certified as reasonably to be expected; continued attendance of the full Panel at these tests was not possible.

Organization of a Field Test

There were two series of meetings required by the Panel to make the first two types of tests. The first series extended from February to April, 1952. An early difficulty encountered was to determine how to run a field test in an orderly and meaningful fashion so as to get a dependable, quantitative evaluation of a system. Much of the effort of this first series of five full dress tests was devoted to solving this problem. Since this was a somewhat painful experience, it may be well to set down some of the practices which it seemed necessary to adopt in order to achieve an orderly determination of the value of a system.

The Panel was hampered in its work by being able to take data off the air only when the station's commercial program was over for the day and so had to work mostly from 1 A.M. to 6 A.M. It was therefore useful to have all preparatory adjustments out of the way in advance.

Signal Certification

Of course, the first requisite was to be sure that the signal which was being received was in fact a suitable one, that is, one which was within the tolerances set down by Panels 13 and 14. A special group (Committee 6 of Panel 16), independent of the Main Panel, was set up for this purpose.

NATIONAL TELEVISION SYSTEM COMMITTEE
DETAIL FIELD TEST REPORT

Test # ____________

Set Manufacturer ____________ Place ____________ Date ____________

Observer's Signature ____________ Channel ____________ Viewing Distance ____________

Room Illumination ____________ Picture Brightness, Highlight ____________ Shadow ____________

Resolution Horizontal Vertical	*Black and White*	*Black and Green*

Test	Scale	Slide A	Slide B	Slide C	Slide D	Color Wheel	Live	Notes
A —Over-all Picture Quality	2							
B —Large Area Flicker	1							
C —Small Area Flicker	1							
D—Brightness	2							
E —Contrast	2							
F —Registration	2							
G—Picture Texture	1							
H—Adequacy of Sync	2							
I —Sound Quality	1							
J —Color Fidelity	2							
K—Color Break-up	1							
L —Color Sync	2							
M—Color Fringing	1	—	—	—	—			
N—Continuity of Motion	2	—	—	—	—			
All Chroma Circuits Off								
D—Brightness	2							
E —Contrast	2							
F —Registration	2							
G—Picture Texture	1							
H—Adequacy of Sync	2							
J —Color Fidelity	2							
N—Continuity of Motion	1	—	—	—	—			

See Instruction Sheet for scoring techniques.

Fig. 2

This group divided the signal specification into three categories as follows:

1. The first category has to do with the general nature of television systems, which are determined at the installation of the transmitter. Included in this category are Scanning Directions and Velocities, Interlacing, Aspect Ratio, Sync Signals, Negative Modulation, Vestigial-sideband Transmission, FM Sound, 75-Microsecond Time Constant, Picture-sound Spacing, Horizontally Polarized Radiation, Taking Characteristics, Gamma Correction, Numerical Relation of Horizontal Deflection, Color-difference Bandwidth, and Color-carrier Bandwidth. Information concerning the fulfillment of these specifications was furnished by the broadcaster, sometimes in the form of measured curves.
2. A second category of the specification has to do with official aspects, involving maintenance of signals within prescribed tolerances, in order to fulfill regulatory requirements imposed on the broadcaster by the FCC. Included in this category are Modulation Envelope, Picture-sound Power Ratio, Color-carrier Frequency, Monochrome Bandwidth, Time Delay, Time Delay Precorrection for Receivers, and Out-of-band Radiation Levels. Again the broadcaster was asked to certify that all transmission conforms to these specifications.
3. The last category concerns the Color Signal Make-up, including color-carrier vector relations and the associated monochrome signal amplitude. Committee 6 developed specialized equipment[4] to measure the conformance of a transmission to these specifications when the transmitter is radiating a standard bar-chart signal.

In general, this group either checked out the signal at both the transmitter and receiver locations the night before the formal tests were to be run, or checked out the transmitter input during early evening and checked out the signal at receiving site immediately the transmitter went on the air with a color transmission.

Measurement Procedure

The arrangement of the sets and the progression of the observers made considerable difference in the amount of confusion generated. With ten sets and some twenty-five observers, it was found essential to conform to a set pattern to avoid chaos. The best system evolved, and one which seemed to make the evaluation of the system relatively independent of observer characteristics, was to locate the receivers roughly in a circle or "U" arrangement, to set up one picture, and to have all observers score all characteristics on all sets (moving from set to set in a predetermined orderly fashion) before making any change at either transmitter or receiver.

Each observer was given a supply of the forms "Detail Field Test Report," Fig. 2, sufficient to mark one for each receiver present, and instructed to fill them out in conformance with "Instructions for Filling Out Detail Field Test Report" (see Appendix A).

The optimum procedure for the tests was decided upon as follows:

1. General tune-up and adjustment on bars, dots, etc., on a closed circuit prior to color broadcast, if possible.
2. Final adjustment of "fine tuning" on a resolution test pattern.
3. Final adjustment of chroma gain and brightness and contrast on a colored slide.[5] Henceforth, adjustments were made to the receivers only in emergency and with permission of Panel officers.
4. Monochrome resolution chart—read and record horizontal and vertical resolution on Fig. 2.
5. Turn off red and blue camera guns—read and record horizontal and vertical detail.
6. Slide—measure highlight brightness, contrast ratio, and ambient illumination. This test was usually made by only two or three observers.
7. Live program[6] (chrominance circuits on)—record data using numerical scales described in section on Compatibility, above.
8. Live program (*all* chrominance circuits turned off)—record data in numerical scale. This test was omitted in some field tests.
9. Color slide chosen by lot (chrominance circuits on)—record all pertinent judgments in numerical scale.
10. Same color slide as in 9 (*all* chrominance circuits turned off)—record all pertinent judgments in numerical scale. (Steps 9 and 10 repeated for as many slides as desired—four were used in the formal test sessions.)
11. Color wheel (chrominance circuits on)—record pertinent data in numerical scale.
12. Color wheel (*all* chrominance circuits off)—record pertinent data in numerical scale.

Formal Color Field Tests

During this first series of field tests, several findings were made:

1. More work had to be done on most of the receivers to permit them to get good pictures.
2. The signal certification equipment required more work to be completely satisfactory.
3. The signal specification left something to be desired. In particular, a serious complaint was registered concerning edge flicker. Panel 13 was advised.

[4] C. E. Page, "A monitoring system for NTSC color television signals," *I.R.E. Convention Record*, part 4, pp. 61–65; March, 1953.

[5] A set of carefully selected colored (Kodachrome) slides was available at each transmitter through the courtesy of the Eastman Kodak Company. The "Sunflower Girl" slide was used for this adjustment of chroma gain.

[6] The only purpose of putting the live program first was to release the live talent as soon after midnight as possible. This would not be important if the viewing were in the normal daylight work hours.

As a result, the Panel decided to discontinue its field tests and devote its members' energy to helping clear up these items. This was in June, 1952. It was not until January, 1953, that Panel 13 proposed a new signal specification for field testing which was adopted by the main NTSC. The principal differences from the former signal were the abandonment of Color Phase Alternation, which had been causing the edge flicker, and the use of the orange-cyan wideband technique in which different colors are processed with different bandwidths. This is a technique to take advantage of the fact that the eye sees small detail better in certain colors than others.

The first field test of the new signal was held at the RCA laboratory in Astoria, L. I., N. Y., on March 18–19, 1953. Two transmissions were available, the NBC transmitter KE2XJV on Channel 4, and the DuMont transmitter KE2XND on Channel 5. Attendance on the first night was 57, on the second 53. Eleven companies had sets as follows:

Admiral	2+1 Reserve
Crosley	1
Emerson	1
General Electric	2
Hazeltine	2+1 Dichroic
Motorola	3
Philco	1
RCA	2 (one bright-tube set)
Sylvania	1
Westinghouse	1
Zenith	1.

The second night of this test was considered the first really satisfactory test of the new signal. Live camera and slide pictures were available over coaxial cable from 8 P.M. on. Air signals were available starting at approximately 1 A.M. Although there was a minor difference between the cable and air signal, both were certified by the Signal Certification Committee. The DuMont signal was not available for certification, due to an incorrect subcarrier frequency. This was later corrected, and a satisfactory color picture and bar chart were received from them at 4 A.M., on March 20, 1953, over Channel 5, too late for formal certification.

Fifteen of the receivers were practically trouble-free. Three had slight troubles such as color instability, and so forth. Marking on a scale of 1 = excellent, down to 6 = not usable, the comments on the first night of this test gave only 8 comments of "6," 35 of "5," 180 of "4," and about 4,250 of either "1," "2," or "3"—the 4,250 figure therefore including excellent, good, or usable. While few of the sets gave really excellent pictures, all of them showed promise that, with a little more experience on the part of the design engineers, they would.

Then followed a group of check-outs on the various transmitters—General Electric, Philco, and Zenith. A few of the better playing sets were selected and taken to Syracuse, Philadelphia, and Chicago, along with the signal-certification equipment. All of these transmitters showed themselves to be substantially satisfactory; minor and correctable deficiencies only were discovered.

The final full dress rehearsal field test was held at the Philco plant in Philadelphia using the Philco transmitter KG2XDT on Channel 3. While no formal data were taken, since there was some trouble in the microwave link and the signal was not actually broadcast, the pictures on the various receivers were so satisfactory that it was decided the shakedown period was over and that the next test would be a formal one at which data would be taken for the record.

This first formal test of the adequacy of the system, therefore, was held at the Bayside, L. I., N. Y., laboratories of the Sylvania Electric Products Company, May 6–7, 1953.

At this test three transmissions were available. One was the DuMont transmitter KE2XDR at 708–714 mc, located at 515 Madison Avenue, New York, N. Y., with 5 kw effective radiated power. The second was the standard DuMont transmitter KE2XND on Channel 5, and the third was the NBC transmitter KE2XJV on Channel 4. The UHF transmitter was used in advance to set up the receivers in the early evening hours while Channels 4 and 5 were both still on commercial broadcasts. The UHF signal was very noisy, since it was received under fairly difficult transmission conditions. A transmitter of this low power, transmitting from the midst of Manhattan (with all its huge buildings), with a non-line-of-sight path over a 13-mile stretch which is intersected by the landing patterns of two of the busiest airports (LaGuardia and Idlewild) in the United States, would seem to offer fringe-area conditions. Indeed, there was considerable surprise that a usable signal was received. It was noted, however, that good color pictures were obtained on almost all sets, and that in no case was the effect of the fringe-area condition on color, in any sense, worse than on black-and-white receivers.

Ten manufacturers furnished sets, as follows:

Admiral	1 (delayed in transit)
Crosley	1
Emerson	1
Hazeltine	2+1 Dichroic
Motorola	1
Philco	1
RCA	2 (one bright-tube set)
Sylvania	1
Westinghouse	1
Zenith	1.

All data for the record were taken between 1 A.M. and 4 A.M. from KE2XJV on Channel 4. The system performed excellently.

On the first night 19 panel members and 36 nonmembers were present. On the second night 63 people, including 19 members, participated.

Committee 6 felt that none of the transmissions on this date was in fact entirely within the limits laid down by Panel 13 and that, therefore, they could not certify any of the available signals. However, since almost all

sets seemed to be giving good pictures on all three transmissions, it was decided to proceed with the field tests to see if, in fact, the tolerances specified by Panel 13 might be closer than really required. During this test, at one time, all receivers were tuned to Channel 5. At one point it was announced that Channel 4 was now on the air, and all receivers were requested to change to Channel 4. All receivers, operating at the time, tuned over to Channel 4 and gave satisfactory pictures thereon without readjustments of the sets being required. This was considered by the Panel as being evidence that the tolerances put on the signal by Panel 13 were, in fact, closer than need be, that the signal was satisfactory for a commercial system, and that two signals, sent out with tolerances somewhat beyond the established limits, could both in fact give good pictures on properly operating receivers without change of adjustment. This again was reported back to Panel 13, who thereupon agreed to widen tolerances of the signal specification.

A subsequent field test was held at the Philco Corporation on May 19–21, in the main building, Tioga and C Streets, Philadelphia 34, Pa. On the first night, 39 people were present. On the second night, 28 observers participated. Manufacturers supplying receivers were:

Admiral	1
Crosley	1
General Electric	1
Hazeltine	2
Motorola	1
Philco	1
RCA	2
Tele King	1
Westinghouse	1
Zenith	1.

Again, 12 receivers of 10 different manufacturers were shown to give good color pictures on the Philco transmitter. In this case, the transmitter was checked and certified to be within the tolerances originally proposed by Panel 13.

Based on these two tests, it was decided that the color signal, under reasonably good conditions, could be depended upon to give good pictures with properly designed and properly operating receivers.

Two additional facts of interest were demonstrated at this field test. In the first place, as a special condition, the Philco receiving antenna was rotated so as to face away from the transmitter and pick up a strong group of echoes from the Camden-Philadelphia Bridge. When the station call letters were on the kinescope, letters appeared in many places on the screen, showing that not one but several echoes were present. It was the consensus of the Panel that the color sets were slightly more susceptible to the effect of multipath than were the monochrome equivalents. This result checks closely with Dr. Fredendall's report, discussed below.

After the antenna was restored to its optimum position, the signals were reduced by some 40 db, so that they were quite noisy. Here again the general Panel judgment was that the color receiver was very slightly more susceptible to the effects of noise than were the equivalent monochrome receivers.

Based on the results of the field tests at Bayside and Philadelphia, it was concluded that, as far as psychophysical tests were concerned, the specification had been shown to be adequate, and that no further field tests of this nature were either required or desirable. Satisfactory pictures had been sent out by five transmitters, and satisfactory pictures had been received on receivers made by at least twelve manufacturers (those having sets at the various field tests; several other manufacturers are known to have built receivers).

On May 27, 1953, the Panel met at the RCA Laboratories in Princeton to discuss and accept a report of a psychophysical test to measure the relative effects of various types of interference on color and monochrome receivers. At this meeting, which was joint with Panel 15, there were 19 members of Panel 16 and 35 nonmembers present. The topics covered were co-channel interference, lower-adjacent-channel interference, upper-adjacent-channel interference, random noise, sine-wave interference, multipath and impulse noise. The psychophysical tests had been carried out by Dr. G. L. Fredendall[2] of the RCA Laboratories Division, with some 25 observers, over a period of three months. Dr. Fredendall's testing had naturally been done completely with RCA equipment. In conjunction with Panel 15, the Panel observed the various average figures which had resulted from Dr. Fredendall's group of observers, and felt that they all appeared to be quite reasonable. Both color and monochrome sets of several manufacturers were present, as follows:

Admiral	1 Color receiver
Crosley	1 " "
Emerson	1 " "
General Electric	1 " "
Hazeltine	1 " "
Philco	1 " "
RCA	1 " "
Tele King	1 " "
Westinghouse	1 " "
Zenith	1 " "
DuMont	1 Monochrome receiver (21")
Emerson	1 Monochrome receiver
Motorola	1 " "
Philco	1 " "
RCA	1 " "

At another series of tests, measurements were made with the American Radio Relay League to determine the difficulty to be expected from bilateral interference between color and monochrome television receivers receiving color transmissions and amateur radio transmitters and receivers in 80-, 40-, and 20-meter bands.

Furthermore, tests were made by introducing 60-cycle hum into the color television receiver to determine its effects. This last was in reality more of a laboratory-type test than a field test.

Results of the Field Tests

The field tests break down naturally into the three broad divisions already considered. First, there are those in which actual numerical values can be obtained. The first of these has to do with the resolution obtainable with color sets. The maximum horizontal resolution obtained on any set was 284 lines against a theoretical maximum of 320. However, the average obtained at one test was 264 lines; at one laboratory an average for current black-and-white sets of various manufacture was measured as 275 lines. The corresponding vertical figures were 346 and 350–397 lines. These represent a degradation of only a few per cent. Undoubtedly, more care will have to be given in the manufacture of color sets, at least with the present display device, but the results do show that, even at this early date, reasonably good resolution can be obtained.

The second measurement was of brightness and contrast. Sets with tricolor-tube displays differed markedly, with brightnesses varying from 6 foot-lamberts up to 28 foot-lamberts. Contrast ratios ranged from 6 to 44 times. To show that there is no added system limitation, a dichroic set (trinoscope slave) was exhibited with brightnesses up to 125 foot-lamberts. No ill effects of this high brightness (such as flicker) were observed.

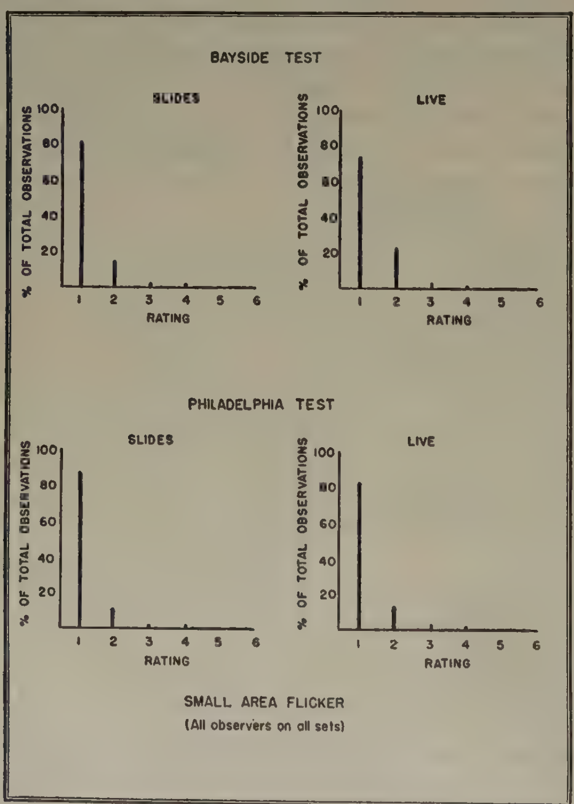


Fig. 3

The second group of test results were those intended to show that the signal specification was capable of making pleasing pictures. Of necessity these were subjective in nature and so required measurements by a group of trained observers. These were made by the Panel members, observers, and other trained personnel at many locations. The results of two of these field tests were analyzed. For many of the characteristics the results even for the present developmental receivers are "good" to "excellent," indicating that production sets will present no serious problem. Such characteristics are Large Area Flicker, Small Area Flicker, Picture Texture, Adequacy of Sync, Sound Quality, Color Break-up, Color Sync, Color Fringing, and Continuity of Motion. See, for example, Figs. 3 and 4 for the distribution charts on Small Area Flicker.

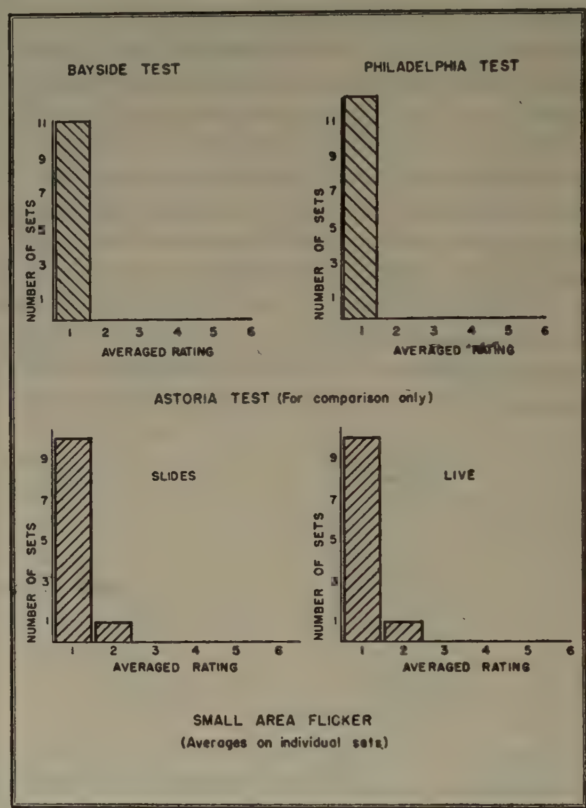


Fig. 4

Of the others, for Brightness and Contrast the limitation is purely one of the display device. The system has been demonstrated at 125 foot-lamberts in an experimental trinoscope with no observable degradation. The present display device is capable of giving reasonably bright pictures now (6 to 28 foot-lamberts), but some increase is desirable.

This leaves Registration, Color Fidelity, and Over-all Picture Quality. Figs. 5, 6, and 7 give the distribution curves for Registration. The deficiency here has in fact nothing to do with the signal specification, since all of the required information is in it. It does, however, point up the requirement for display devices which are simpler to bring in register, or for increased skill on the part of the technician.

Figs. 8, 9, and 10 give the distribution curves for Color Fidelity. The results tend to cluster around "good" to "passable." Two set averages are "not quite passable." This is the only simple characteristic for which such poor averages occur. It is also the only sim-

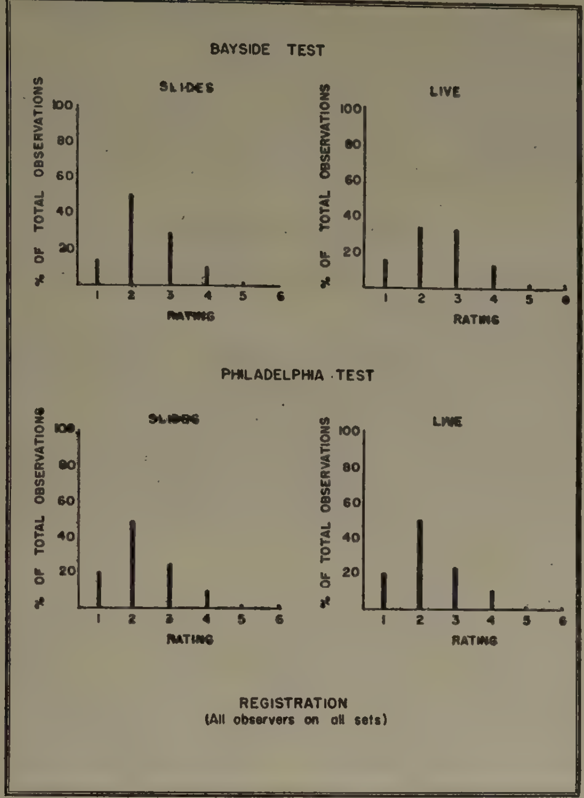


Fig. 5

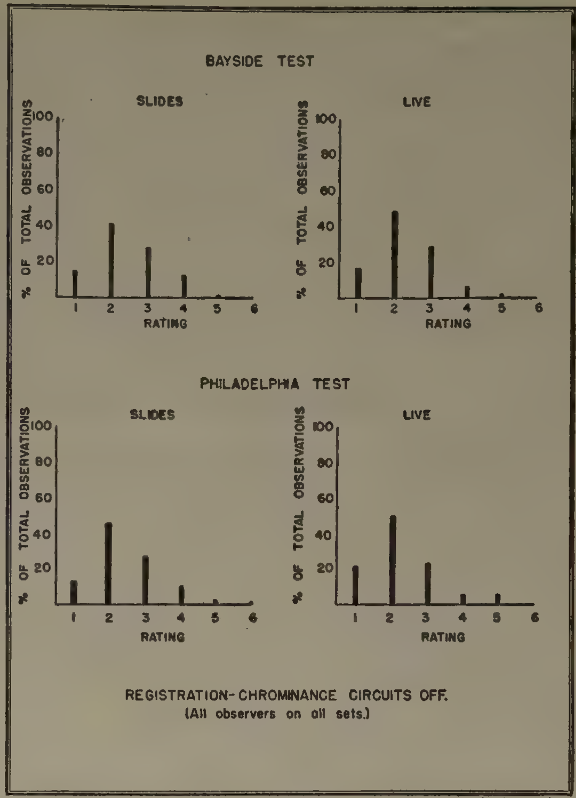


Fig. 6

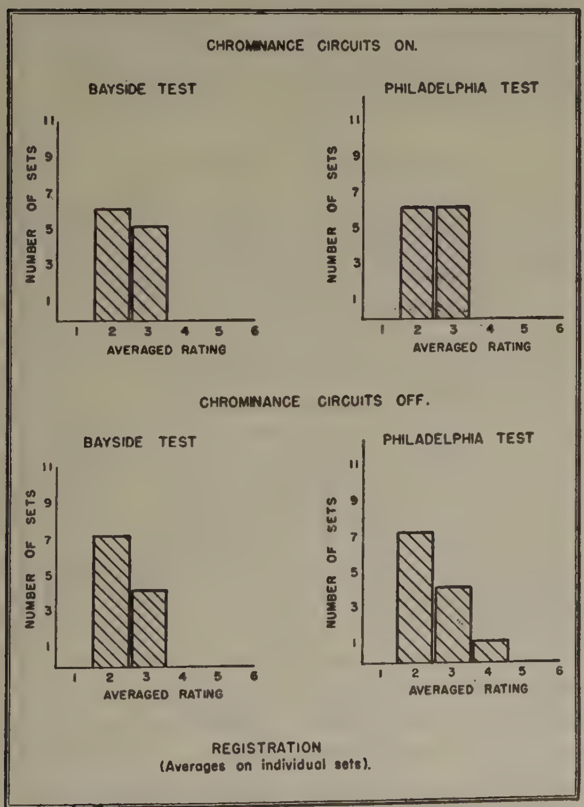


Fig. 7

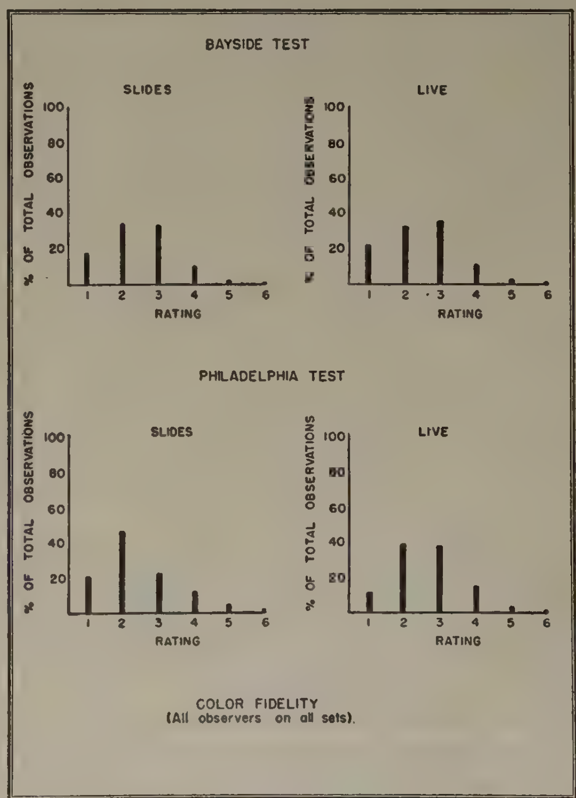


Fig. 8

ple characteristic for which such large standard deviations of the distribution curves occur. There are several reasons for this. One undoubtedly is the difficulty of adjustment of the display device. Another is the fact that the critical adjustments were made by engineers, who are not color specialists.

The most important factor is probably that judgments differ as to what is good color. On a single set, in a single test, judgments of individuals ranged from "excellent" to "poor." There was no consistency among observers. One observer would mark low on one set but would be higher than average on another. This seems to be a case of one man's meat being another man's poison.

This is not too surprising when notice is taken of the large differences of opinion among the public in judging the paintings of even the best artists. Furthermore, in monochrome television, some people have bought bluish filters to put over their picture tubes, while at least one manufacturer has marketed sets with a yellow filter in front of the display.

Probably the only conclusion that can be reached is that Color Fidelity is a highly subjective matter, and that possibly no setting will prove pleasing to all of a group of critical observers. This need not be too disturbing, for the successes of color motion pictures and color photography show that most people are not critical observers, and that color does in fact add to the pleasantness of a picture.

The similarity of the curves of Figs. 11 and 12 to those of Figs. 8, 9, and 10 leads one to believe that the main reason for the deficiencies found in Over-all Picture Quality is associated with Color Fidelity and that the remarks made above in connection with Color Fidelity apply here. (Figs. 11 and 12 appear on page 35.)

Altogether, it was the consensus of the Panel that the system is capable of making highly pleasing pictures and future improvements will make them better.

The remaining group of tests has to do with the vulnerability of the system to various forms of interference. The first of these is Fringe Area Operation. This test has been made three times under actual conditions: (1) at Morrisville, Pa., in February, 1952, at a location adjacent to a main highway, where Channel 4 was picked up 60 miles away; (2) at the Zenith plant, on April 10, 1953, where a broadcast from a low-power transmitter in downtown Chicago with non-line-of-sight transmission gave extremely noisy signals; and finally, (3) on May 5–8, 1953, when the DuMont UHF transmission was under quite difficult conditions. In no case was the color set degraded markedly more than a monochrome set under the same conditions.

The tests on Co-channel Interference, Adjacent Channel Interference, Susceptibility to Impulse and Random Noise, and to Sine Wave Interference were all run by the Ad Hoc subcommittee. The results are given in the section on Compatibility.

The test on Susceptibility to Hum showed that for a color set displaying a color picture, the effect of hum on the color set was no greater than on a monochrome set. For a color set displaying a monochrome picture, hum was slightly more degrading. Reasonable filtering will take care of the problem.

The five tests made on bilateral interference between amateur equipment and color television receivers demonstrated that, while there is a serious problem, it is susceptible to the usual engineering approaches of shielding, traps, separation, and so forth.

Thus, as far as color broadcasts and receivers are concerned, there seems to be no bar to the immediate standardization of the NTSC color signal specification and the introduction of commercial color broadcasting.

Broadcast System[7]

The field test responsibilities of Panel 17 lay in three main areas as follows:

1. Network transmission of the proposed color signal.
2. Transmission of the proposed signal through existing commercial monochrome transmitters.
3. The feasibility of building live pickup equipment to produce the proposed color signal possessing the necessary operational flexibility for broadcast service to the public.

Since the basic aim of the NTSC field test activity was to test the potentiality of the proposed signal specification for rendering broadcast service, independent of equipment performance in the current state of the art, it was necessary to devote considerable attention to planning the kind of field tests which would be most meaningful. Obviously, it is impossible completely to divorce equipment testing from testing of the signal characteristics in any practical operational field test, but it was desired that this be done to the extent feasible. For this reason much of the early activity of the Panel concerned itself with developing test specifications which would best meet this objective.

Network Transmission

In the first area of activity, that of network transmission, a Committee on Network and Transmission was formed to develop the detailed test specifications. This committee in a series of meetings worked out a set of test specifications, a data report form for individual observers to record results during field tests, and a set of instructions for observers using the data report forms. The committee borrowed freely from the work and experience of Panel 16 in the preparation of both the test specifications and the data report forms, but it was necessary to tailor these to the special requirements of network transmission testing. An important difference between the field testing of Panel 16 and that of Panel 17 is that for the most part Panel 16 results were scored as over-all evaluations of final performance, whereas in testing network transmission Panel 17 decided against duplication of the tests carried out by Panel 16 with merely the addition of a network transmission link in the system. Instead, since it was feasible to conduct the network tests on looped circuits, these tests were made on a comparative basis, and observers scored the effect of adding the network loop instead of scoring over-all quality. This, it is believed, resulted in

[7] Prepared by R. E. Shelby, Chairman of Panel 17.

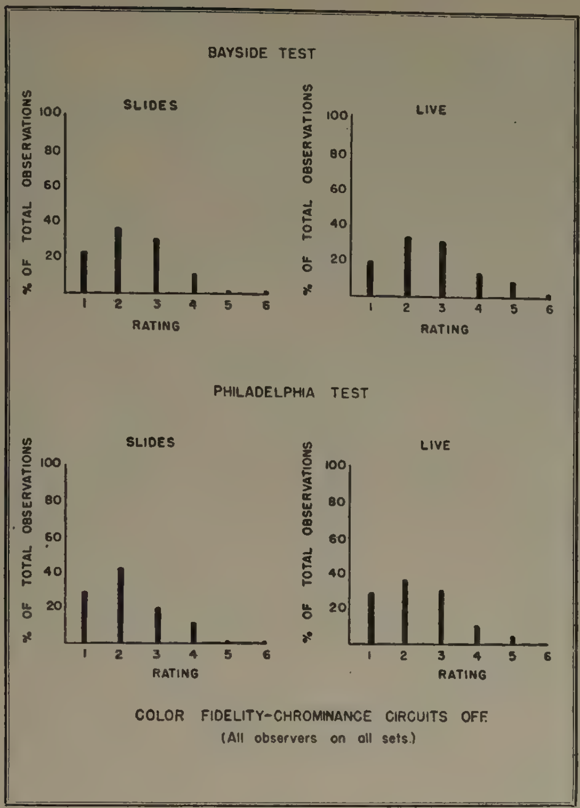


Fig. 9

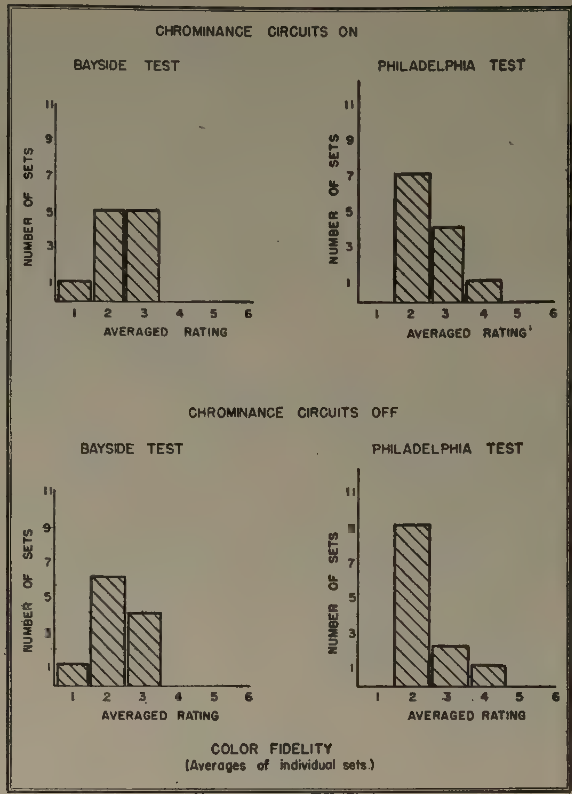


Fig. 10

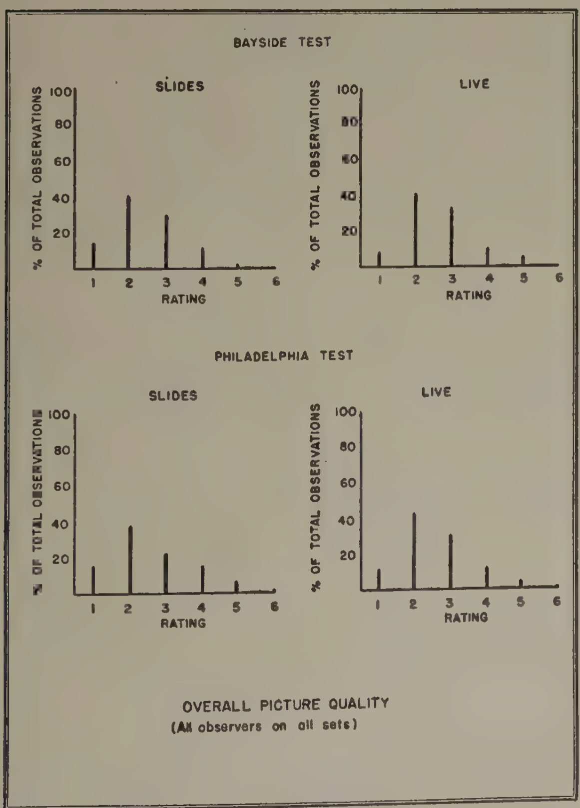


Fig. 11

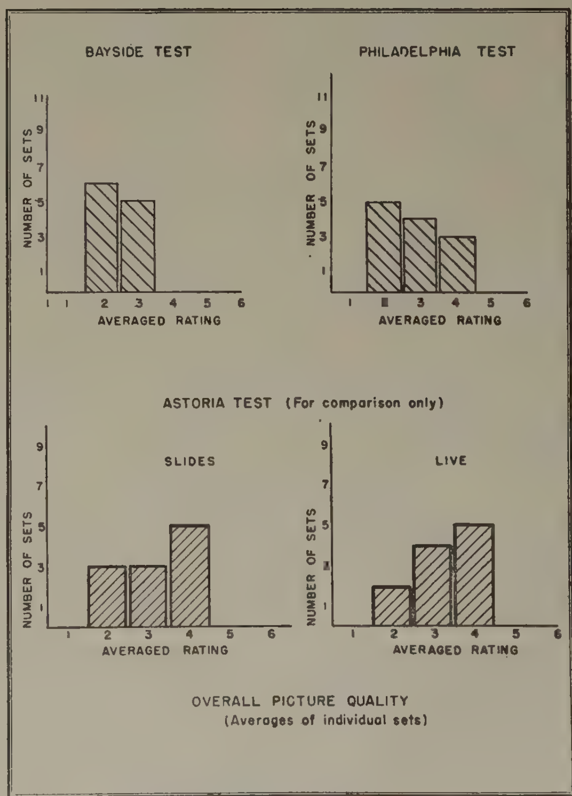


Fig. 12

a more critical and accurate evaluation of the effects of network transmission independent of any variations in original signal quality or other vagaries, since the same viewing screen was switched several times during each separate test between a direct feed and a feed that included the network loop using the same signal.

Fig. 13 is a reproduction of the detailed test report form on which observers scored their ratings in the network field tests. It will be seen that a great many of the characteristics tested are the same as those tested by Panel 16. The same numerical scales for rating performance qualitatively were used in this scoring as were used in the field test of both Panel 15 and Panel 16, and these scales are described in more detail in the section on compatibility field testing. (The scales are given at the end of the Test Report Form—Fig. 13.) It is important to note again that in the case of this network field testing, the score given in each case represented an evaluation of the effect of adding the network loop—not an evaluation of the over-all result.

Experience shows that more meaningful and reliable results can be obtained in a field test of this complexity if all observers have given some time to studying the procedures so that they thoroughly understand the

PANEL 17—BROADCAST SYSTEM
NATIONAL TELEVISION SYSTEM COMMITTEE
DETAIL NETWORK TEST REPORT

Transmitting Equip Location ______
Viewing Location ______ Viewing Distance ______
Network Facility—Type ______ From ______
To ______
Receiver/Monitor—Color ______ Monochrome ______
Room Illumination ______ Picture Brightness, Highlight ______ Shadow ______
Resolution (Black & White) Color Rec. ____H. ____V. Monochrome Rec. ____H. ____V.
Resolution (Black & Green) Color Rec. ____H. ____V. Monochrome Rec. ____H. ____V.
Overall Picture Quality Before Transmission (Use Scale 2) ______
Special Equip (if used) ______
Observer's Signature ______ *Company* ______ Date ______

Test (Use Scale 1)	Slide				Color Wheel	Live	Notes
	A	B	C	D			
A —Over-all Pix Quality							
B —Large Area Flicker							
C —Small Area Flicker							
D —Brightness & Contrast							
E —Registration							
F —Picture Texture							
G —Color Fidelity							
H —Color Break-up							
I —Color Sync							
J —Color Fringing							
All Chroma Circuits on							
All Chroma Circuits off							
K—Continuity of Motion							
All Chroma Circuits on							
All Chroma Circuits off							
L —Adequacy of Sync							
All Chroma Circuits on							
All Chroma Circuits off							
M —Streaking and Smearing							
All Chroma Circuits on							
All Chroma Circuits off							
N —Echoes							
All Chroma Circuits on							
All Chroma Circuits off							
O —Interference							
All Chroma Circuits on							
All Chroma Circuits off							

Scale 1		Scale 2
Degradation not perceptible	1	Excellent
Just perceptible	2	Good
Definitely perceptible, but not objectionable	3	Passable
Somewhat objectionable	4	Not quite passable
Definitely objectionable	5	Poor
Not usable	6	Not usable

Fig. 13

basis for evaluation of results and also have had a certain amount of practice in judging the results and recording data. For this reason the detail field test specifications and report forms were mailed to all Panel members in advance of the field test with a request that they study them—particularly the instructions for filling out the detail field test report form worked out by the Committee on Network and Transmission. These instructions are reproduced in Appendix B as an example of the thoroughness with which preparations were worked out in advance of the field tests. The Panel also had a preliminary field test session on March 27, 1953, at which no data were taken for the record. Members and observers had an opportunity on that occasion to rehearse their participation in this type of test in preparation for the formal field tests.

Inter-city video program transmission circuits supplied by the American Telephone and Telegraph Company for regular monochrome service are of two types—the type TD2 microwave circuit which has a nominal bandwidth of approximately 4 mc, and the type L1 coaxial cable circuit which has a nominal bandwidth of approximately 2.7 mc. Panel 17 carried out field tests on looped circuits of both these types. In both cases the loops were between New York City and Washington, D. C. In these field tests the question naturally arose as to the precise transmission characteristics of the circuits tested at the time the tests were made, and this matter was the subject of very careful consideration by the Panel and by the Bell System. The circuits used for these tests were the regular Bell System inter-city video circuits and local program circuits employed in commercial television network service, but for these field tests Bell System engineers supplied special equalization of both phase and amplitude not normally furnished for monochrome service in order that the actual characteristics of the circuits would approximate more closely the ideal characteristics. This special equalization in no way degraded the circuits for monochrome program transmission, but in fact provided, at least theoretically, somewhat improved monochrome transmission, although such improvement for monochrome would not be as important as for color transmission. Appendix C attached hereto is a report concerning the characteristics of the circuits used in these field tests.

Field tests of both the microwave loop and the coaxial cable loop were made by the Panel on June 10, 1953, employing color signals originating at the RCA-NBC color television studio in the Colonial Theatre in New York, and results were viewed by the Panel on experimental, home-type, RCA color receivers fed by closed circuit through RF signal generators in viewing rooms at the Center Theater in New York. The line drawing of Fig. 14 shows schematically the setup employed in this field test. As will be seen from this drawing, it was arranged to switch the monitoring receivers to receive a signal directly from the originating studio, or to receive it after transmission to Washington, D. C., and return over either a TD2 microwave circuit or an L1 coaxial cable circuit. Such switches were made frequently for comparison purposes throughout the field tests in order that the observers might evaluate the effect on picture quality of including the inter-city network transmission loop.

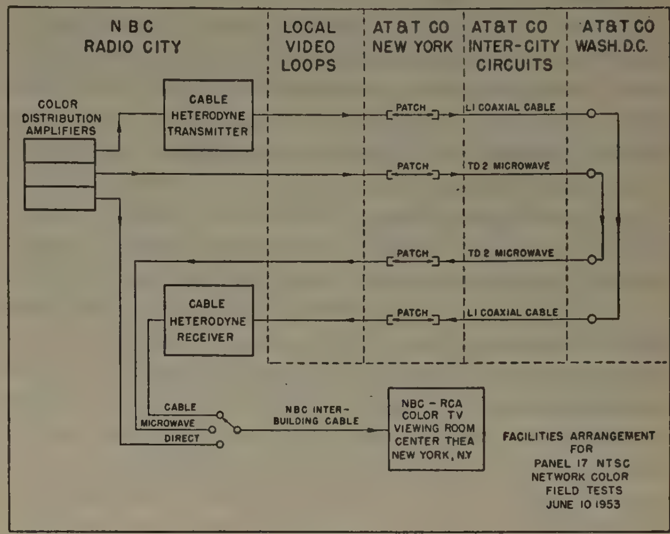


Fig. 14

All feasible precautions were taken to insure that the color signal employed for the field tests met the signal specifications prescribed by NTSC, and in this connection it was deemed advisable to have a special committee measure the signal at its point of origination shortly before the field tests were run. For this purpose arrangements were made for the services of the same Signal Certification Committee established by Panel 16 for this purpose. As reported in the section on color receivers (Panel 16), this committee developed and utilized special equipment to measure the phase relationships and amplitudes of the various signals to determine that they were within the specifications adopted by NTSC.

Results of the June 10, 1953, field test on the type TD2 microwave circuit were very conclusively favorable. Eighteen panel members and observers participated in the test and filled in detail network test report forms of the kind shown in Fig. 13, on which they rated the various characteristics in accordance with the numerical rating scales shown. The scoring given by all observers for each test was averaged arithmetically, and it was found that every one of the averages lay numerically between 1.00 and 2.00, showing that addition of this microwave network loop resulted in degradation with regard to the various characteristics listed in Fig. 13, which on the average was somewhere between "not perceptible" and "just perceptible." This result confirmed the consensus of the Panel in its earlier rehearsal test of March 27, 1953.

On June 10, 1953, the Panel also carried out a field test on a type L1 coaxial cable circuit looped between New York City and Washington, D. C., using the same

test procedures and the detail network test report form. In this case, as shown by the line drawing of Fig. 14, the transmission loop to Washington included special cable heterodyne equipment developed by RCA to enable transmission of the color information over the narrow band circuits. This equipment has been described in a paper by J. G. Reddeck.[8]

As was to be expected, the degradation produced in the color signal by transmission over the type L1 coaxial cable loop was substantially greater than that produced by transmission over the type TD2 microwave circuit. Coaxial cable test results, during the test of June 10, 1953, were considered to be somewhat poorer than those obtained during the rehearsal test of March 27, and since the scoring was marginal on such transmission characteristics as Color Fidelity and Over-all Picture Quality, it was decided to hold another field test involving transmission of the coaxial cable loop, and this was done on June 25, 1953. Results obtained on this second test were appreciably better than those obtained on the test of June 10, 1953, although they did not, of course, come up to the results of the wide band microwave circuit test. Average ratings given by all observers on two of the important characteristics for these two field tests of the coaxial cable may be of interest. Each characteristic was tested with several different scenes, both from live pickup cameras and a slide scanner,[9] and a separate rating was given for each scene by every observer. If we take an average of the average scores for all observers on the characteristic "Over-All Picture Quality," a composite average of 3.11 is obtained for this characteristic for the test of June 10, 1953, and a corresponding score of 2.72 is obtained for the same characteristic for the test of June 25, 1953. Remembering that a rating of 3.00 is "Definitely Perceptible, But Not Objectionable" and a rating of 4.00 "Somewhat Objectionable," it is seen that the composite, over-all rating of all observers with regard to this characteristic for the coaxial cable circuit is certainly marginal but probably acceptable.

In the case of another important characteristic, that of Color Fidelity, a composite averaging of the average scores of all observers for the test of June 10, 1953, gives a score of 3.15, which is slightly poorer than "Definitely Perceptible, But Not Objectionable." For the test of June 25, 1953, the composite average score for this characteristic was 2.58, which is about midway between "Just Perceptible" and "Definitely Perceptible, But Not Objectionable."

In assessing the above results reported by the Panel, it is important to remember that these are judgments rendered by a group of highly skilled technical observers possessing unusual training and experience in this field. Experience has shown that the ratings of the general public with regard to technical quality of television pictures—both monochrome and color—are substantially higher than the ratings of such technically trained observers.

On the basis of these field tests of the two types of inter-city circuits, Panel 17 stated in its Final Report that "The Panel has determined that the proposed NTSC color TV signal specifications (as adopted on January 15, 1953 and revised on June 24, 1953) will result in a signal which . . . can be satisfactorily transmitted from city to city by means of existing, and suitably equalized, inter-city microwave program circuits of the Bell System. The Panel has also determined that by the use of special heterodyne equipment a signal derived from the proposed NTSC color signal can be transmitted over the Bell System's L1 coaxial cable circuits, suitably equalized, which will result in a received signal having a quality acceptable for color TV reception though perceptibly degraded."

Transmitters

In this area of the Panel activity a Transmitter Committee was established to study and report on the transmission of the proposed color signal through existing commercial monochrome transmitters. This committee held a number of meetings and submitted a formal report to the Panel. An important part of this Transmitter Committee report consisted of detailed information furnished by transmitter equipment manufacturers on the modifications necessary in their standard commercial transmitters to provide adequate broadcast transmission of the proposed NTSC color signal.

At its meeting on June 25, 1953, Panel 17 witnessed reception of color signals on experimental color receivers located at the RCA Receiver Laboratory in Long Island City, N. Y., as transmitted over experimental station KE2XNK, operating on Channel 11 in New York. The color signals for this test originated in the Colonial Theatre and consisted of special test signals, standard slides and live subjects. Picture quality received over Channel 11 was compared with that received from a RF signal generator fed over a video wire circuit from the studio. In addition to the field test transmission which Panel 17 witnessed over Channel 11, cognizance was taken of the several field tests conducted by Panel 16 involving transmission of the proposed color signal over several different transmitters in several different cities, and reception on experimental color receivers designed, constructed and operated by a number of different receiver manufacturers.

As a result of its own field tests, the report of the Transmitter Committee, and its knowledge of the field tests conducted by Panel 16, Panel 17 concluded that the proposed color TV signal can be satisfactorily broadcast by present TV broadcast transmitters with only relatively minor changes.

[8] J. G. Reddeck, "Narrow band transmission of the NTSC color signal," Proc. I.R.E., pp. 90–91, this issue.

[9] The slides used in these tests were selected by lot from the series of standard (Kodachrome) color slides made available for NTSC testing by the Eastman Kodak Company.

Operational Flexibility of Pickup Equipment

It is one thing to generate a test signal in a laboratory for technical testing from a slide scanner or electronic signal generating circuit, but it is quite another matter to provide the cameras and associated equipment needed in a broadcast service for televising a complex and rapidly moving live-talent program which also produce an electrical signal meeting the specifications. One of the assignments given to Panel 17 was to investigate this point with respect to the proposed NTSC color TV signal—in other words to determine whether or not there was a reasonable prospect of manufacturing color television pickup equipment which would meet the needs of the broadcaster with respect to operational flexibility under practical operating conditions, while producing an electrical signal meeting the proposed specifications.

During the meeting of Panel 17 on June 10, 1953, just prior to the formal field tests of the inter-city network circuits, the Panel witnessed a live color program originating at the RCA-NBC Colonial Theatre, 53 West 62 Street, New York, N. Y. This program was planned to illustrate the capabilities of the pickup equipment used as regards operational flexibility. It involved closeups and long shots, brightly lighted scenes of high chroma, subdued lighting, rapid switching between three cameras and fast physical motion of cameras. Later the same day the Panel went to the Colonial Theatre and witnessed an operational demonstration of the color pickup equipment, switching and monitoring and control equipment used in the studio for transmitting the program and field test signals. On the basis of these program and operational tests, the Panel decided "... that it has been successfully demonstrated that live pickup equipment can be built to generate signals in accordance with the currently proposed NTSC signal specifications and that from the point of view of over-all performance, this equipment provides operational flexibility comparable to that of present-day monochrome studio equipment and signal quality satisfactory for a broadcast service to the public."

From the foregoing it is seen that the various committees and field test activities of Panel 17 led to the conclusion that so far as broadcast system problems are concerned, the proposed NTSC color TV signal specification will result in a signal which is satisfactory for a color TV broadcast service.

Conclusions to Be Drawn from Field Tests

As a result of these extended series of field tests two conclusions were reached. The first was that a signal specification has finally been evolved which is believed the best obtainable. It was shown to give satisfactory pictures, even under difficult transmission conditions and with present-day equipment. It was also shown not to cause undue disturbance to established services. It was therefore certified to the National Television System Committee as a suitable signal specification on which a satisfactory color television broadcast system could be based.

The second conclusion was as to the absolute necessity of conducting exhaustive field tests before standardizing a public service. During the field tests it was shown imperative to make several major changes in a signal specification which had been found to be optimum in laboratory tests. The synchronizing pulse had to be widened from 0.06 H to 0.08 H; the pedestal had to be removed from under the color subcarrier synchronizing burst; the frequency of the color subcarrier and of the line scanning rate had to be modified to avoid an annoying beat in some sets; and the whole concept of Color Phase Alternation had to be abandoned. Furthermore, certain tolerances which had appeared necessary in the laboratory tests were shown to be unnecessary and unduly restrictive by the field tests.

A subsidiary lesson learned from the field tests by those concerned in them was just how exhaustive a really thorough field test can be. It is estimated that some 25,000 engineering man-hours were involved.

Appendix A

NTSC Panel 16

Instructions for Filling Out Detail Field Test Report

1. Space for set manufacturer shall be filled in by either name or initials as appropriate. Model number should be included if available. Any type of display other than a tricolor tube being judged should be noted.

2. Place and date shall be filled in in sufficient detail to avoid any possible confusion between two sets of tests. If two tests are made in the same city at different addresses or different times of the day, the designation should be unmistakable.

3. Observer's full signature should be on all sheets since these are the raw material for legal documents.

4. The channel may be identified by number or station call letters or both.

5. The observer should sit at a normal comfortable distance from the set. The viewing distance at which judgments were recorded should be specified in terms of picture height.

6. The general room illumination and the high light and shadow brightness for slides 1, 7, and 15 shall be recorded in foot lamberts for each set.

7. Horizontal and vertical resolution shall be measured in number of lines for a black and white test chart with every observer scoring every set unless instructed otherwise. Instructions will then be given to the transmitter to turn off the red and blue pickups and the measurement will then be repeated for black against green.

8. One slide from Group A will be chosen by lot and displayed. The slide number should be entered in the capital A column. Every observer should score every set for all phases of normal operation. See Scoring Technique of this instruction below. The meanings of the individual tests are discussed as follows:

(A) Over-all Picture Quality. This line is simply to sum up the general impression which the picture makes on the observer and provide an opportunity under "notes" to explain why. For instance, it may be that if excessive noise is present, the over-all quality of the picture will be judged unsatisfactory. In such a case it may well be that measurements of Small Area Flicker, Registration, and Picture Texture will be utterly meaningless. In such a case the Over-All Picture Quality should be given a suitably low score with the comment "excessive noise" under notes and the other spaces should have dashes entered to indicate that under the circumstances a judgment of this particular quality was not feasible. Other instances might be poor focus, intolerable misregistration, streaking, 900 kc beat, and other set defects. (Scale 2)

(B) Large Area Flicker. Particular attention should be paid to large areas of saturated color. Observers should look some 45 degrees away from the set to determine if flicker can be determined from the corner of the eye. (Scale 1)

(C) Small Area Flicker. This includes both inter-dot flicker caused by color subcarrier in the luminance channel and edge flicker caused by cross coupling between the color channels. (Scale 1)

(D) Brightness. This is a subjective measurement to determine whether, under the circumstances, the picture seems adequately bright. (Scale 2)

(E) Contrast. This is a subjective measurement to determine whether, under the circumstances, picture seems to have adequate contrast. (Scale 2)

(F) Registration. The purpose of this test is to observe the degree of registration (or convergence) of the reproduced picture. Particular attention should be paid to sharp edges. (Scale 2)

(G) Picture Texture. Look for dot structure, moiré, or other beat pattern. Precaution must be taken to recognize and record any limitations of the subject matter, transmitter pickup equipment, or receiver display which may introduce picture texture that is not a fundamental part of the transmitted signal. If texture is poor, disable all chrominance circuits and reobserve. (Scale 1)

(H) Adequacy of Deflection Synchronizing. The picture should be observed to determine the adequacy of the synchronizing arrangements under the conditions of the tests. (Scale 2)

(I) Sound Quality. The effect, if any, of chrominance information on sound performance shall be evaluated. (Scale 1)

(J) Color Fidelity. Color Fidelity is the degree to which the television receiver appears to reproduce the color of the original scene. Particular attention should be paid to contamination of one color by another. (Scale 2)

(K) Color Breakup. Color Breakup, for the purpose of this test, is defined as any spurious color caused by a difference in the conditions of observations from one field to the next. The observer shall note the presence or absence of color breakup during voluntary motion of the head, motion of the fingers across the picture, and during rapid blinking of the eyes. (Scale 1)

(L) Adequacy of Color Synchronizing. The picture should be observed to determine the adequacy of the synchronizing. (Scale 2)

(M) Color Fringing. Meaningless in this test.

(N) Continuity of Motion. Meaningless in this test.

9. With the chrominance circuits at the transmitter and the receivers turned off, certain of the above measurements are to be repeated.

(A) Color Fidelity. Color Fidelity is to be judged by whether the picture is actually a black, gray, and white one, or whether some other hues are visible

10. The above series of measurements are to be repeated for a slide from Group B, a slide from Group C, and a slide from Group D.

11. A color wheel or similar fast moving object should be viewed with the live camera, first with color circuits turned on, and then turned off, both at the transmitter and receiver. Two additional tests now become pertinent.

(M) Color Fringing. Color Fringing, for the purposes of this test is defined as spurious colors introduced into the picture by change in position of the televised object from field to field. (Scale 1)

(N) Continuity of Motion. Note the presence or absense of the illusion of continuity of motion. With fast motion note whether any beat patterns are worse with the chrominance circuits on or the chrominance circuits off. (Scale 2)

12. The entire series of tests shall be repeated with the camera viewing live subjects.

13. The following tabulation lists the standard slides by group, number, and name for reference purposes.

Group A—Close-up

1 Sunflower Girl
2 Kitten Girl
3 Watermelon Girl
4 Goose Girl
5 Birthday-cake Girl

Group B—Semi-close-up

6 Aviator
7 Crayon Boy
8 Sailing Pair
9 Hawser Man
10 Table Tennis Pair
11 Boat-ashore Pair

Group C—Distant Shots

12 Tug-of-War
13 Tulip Garden
14 Canoeing Boys

15 Winter Sleigh Ride
16 Southern Manse

Group D—Special

17 Lamp-shade
18 Pumpkins
21 Fishing Tackle
23 Meshes
24 Motion.

Scoring Technique

Listed below are two scales to be used for scoring. Two scales are included since the tests are so written that a single scale is not readily usable. The instruction sheet includes notations as to which scale is to be used for each test.

TABLE V

Scale 1		Scale 2
Degradation not perceptible	1	Excellent
Just perceptible	2	Good
Definitely perceptible but not objectionable	3	Passable
Somewhat objectionable	4	Not quite passable
Definitely objectionable	5	Poor
Not usable	6	Not usable

Appendix B

NTSC Panel 17

Instructions for Filling out the Detailed Network Test Report[10]

1. All spaces should be filled in as completely as possible.

2. The space for the network facility should include the designation assigned by the Telephone Company as well as the circuit routing.

3. The space for the receiver/monitors should include the manufacturer's name or initials, model number and picture size.

4. The observer should sit at the normal comfortable distance from the set. The viewing distance at which judgments were made should be specified in terms of picture height.

5. The room illumination and picture brightness should be recorded in foot lamberts.

6. The horizontal and vertical resolution should be measured in the number of television lines using a black and white test chart. The red and blue pickups shall then be turned off and the measurements repeated for black against green.

7. The space for recording the over-all picture quality *before* network transmission is to sum up the general impression which the color picture makes upon the observer. A space for recording the over-all picture quality *after* network transmission is provided under one of the individual tests.

8. The space for listing "Special Equipment" should be used when such items as cable conversion equipment are necessary for the transmission tests; otherwise, use the word "none."

9. One slide from *Group A* should be chosen by lot and displayed. The number of the slide chosen should be entered immediately underneath the capital "A" column. The meaning of the individual tests are discussed below.

(A) *Over-all Picture Quality:* This subjective measurement is to sum up the general impression which the effect of network transmission of the picture signal makes upon the observer and provides an opportunity under "notes" to explain why. For instance, it may be that if excessive noise due to network transmission is present, the Over-all Quality of the Picture will be judged to be unsatisfactory. In such a case it may well be that measurements of Small Area Flicker, Registration, and Picture Texture will be meaningless. In such a case the Over-all Picture Quality should be given a suitably low score with the comment "excessive noise" made under notes. The other spaces should have dashes entered to indicate that under the circumstances a judgment of this particular quality was not feasible.

(B) *Large Area Flicker:* The effect of network transmission should be rated and observers are instructed to look some 45 degrees away from the set to determine if flicker can be determined from the corner of the eye.

(C) *Small Area Flicker:* The effect of network transmission on flicker in small areas is to be rated. This also includes Inter-Dot Flicker caused by color subcarrier in the luminance channel and edge flicker caused by cross coupling between the color channels.

(D) *Brightness and Contrast:* These are subjective measurements to determine the effect of network transmission on brightness and contrast.

(E) *Registration:* The purpose of this test is to determine the effect of network transmission on Registration or convergence on the reproduced picture. Particular attention should be paid to color boundaries and between light and dark-areas.

(F) *Picture Texture:* The effect of network transmission on Picture Texture is to be rated. The observer should look for dot structure, moiré, or other beat patterns not in the picture before transmission over network facilities.

(G) *Color Fidelity:* This test is to determine the effect of network transmission on Color Fidelity. The observer should pay particular attention to color shifts over large areas and to color contamination at boundaries.

[10] Prepared by Network and Transmission Committees.

(H) *Color Break-up:* This test is to determine the effect of network transmission on Color Breakup. The observer should note the presence or absence of Color Breakup during motion of the head, motion of the fingers across the eyes, and during blinking of the eyes.

(I) *Color Sync:* The purpose of this test is to determine the effect of network transmission upon adequacy of color synchronization information.

10. The above series of measurements should be repeated for a slide selected from *Group B*, a slide from *Group C*, and a slide from *Group D*.

11. Slide "A" should now be used with all chroma circuits turned on, then with all the chrominance circuits turned off for the following tests:

(l) *Adequacy of Sync:* The purpose of this test is to determine the effect of network transmission on the ease which the observer can adjust the deflection synchronization of the receiver/monitor. Observations should be made with all the chrominance circuits turned on, then with all the chrominance circuits turned off.

(m) *Streaking and Smearing:* This test is to determine the effect of network transmission on streaking and smearing. Ratings should be made with all the chrominance circuits turned on, then with all the chrominance circuits turned off.

(n) *Echoes:* The effect of echoes due to transmission over network facilities is to be rated. Observations should be made with all the chrominance circuits turned on, then with all the chroma circuits turned off.

(o) *Interference:* The effect of interference picked up in the network transmission facilities is to be rated. Observations should be made with all the chrominance circuits on, then with all the chrominance circuits off.

12. Tests l, m, n, and o shall now be repeated for slide "B," slide "C," then slide "D."

13. The entire series of tests shall now be repeated with the camera viewing a color wheel, a similar fast moving object including tests j and k. The purpose of these latter two tests is to determine the effect of network transmission on

(1) Production of spurious colors at the boundaries of moving objects; and

(2) On the illusion of smooth motion.

14. The entire series of tests "a" to "o" shall be repeated with the camera viewing live subjects.

15. The following tabulation lists the standard slides by group, number, and name for reference purposes.

Group A—Close-up

1 Sunflower Girl
2 Kitten Girl
3 Watermelon Girl
4 Goose Girl
5 Birthday-cake Girl

Group B—Semi-closeup

6 Aviator
7 Crayon Boy
8 Sailing Pair
9 Hawser Man
10 Table Tennis Pair
11 Boat-ashore Pair

Group C—Distant Shots

12 Tug-of-War
13 Tulip Garden
14 Canoeing Boys
15 Winter Sleigh Ride
16 Southern Manse

Group D—Special

17 Lamp Shade
18 Pumpkins
21 Fishing Tackle
23 Meshes
24 Motion.

Appendix C

American Telephone and Telegraph Company
Long Lines Department
32 Avenue of the Americas
New York 13, N.Y.

June 22, 1953

Mr. Robert E. Shelby
Chairman, Panel 17
National Television Systems Committee
30 Rockefeller Plaza
New York 19, N.Y.

Dear Mr. Shelby:

Attached are data sheets giving the measured characteristics of the facilities provided for the National Television Systems Committee color transmission tests on June 10, 1953.

The test over radio facilities utilized a TD-2 television channel on the direct route from New York to Garden City, connected at IF to a channel from Garden City to New York via Clarks Knob. The coaxial test utilized a New York–Washington and a Washington–New York L1 coaxial television channel, connected at line frequency at Washington. Special equalization was applied to both radio and coaxial facilities to modify their transmission characteristics.

At New York, four local loops were used between N.B.C. and NR, each consisting of shielded cable pairs equipped with A-2 video amplifiers.

Very truly yours,
/s/ J. R. Rae
General Methods Engineer

JRR-EVS
Attached:
Measured Characteristics (see top page 43).

NTSC Color Tests, June 10, 1953

Measured Transmission Characteristics of Network Facilities Involved

Gain-Frequency Characteristic

Interexchange Channel TD-2 Radio Loop New York—Garden City-Clarks Knob-New York—Total Length 538 Miles

Frequency kc	Deviations db
10	0
100	0
500	+0.2
1000	+0.2
1500	+0.1
2000	−0.5
2400	−0.4
3000	+0.3
3600	0
4000	−0.1
4200	−0.2

	Radio	Local Channels
Env. Delay (1) (Microsecs.)	±0.1	±0.15
3.6 mc Phase Shift (2) (Degrees)	+2.5	+1.6

Associated Local Channels A2 Video Facilities Total Length 8.35 Miles

Frequency kc	Deviations db To NBC	Deviations db From NBC
5	+0.3	+0.3
10	0	0
25	0	−0.2
50	+0.2	+0.1
75	0	+0.1
100	0	+0.1
150	+0.1	+0.1
200	−0.05	0
250	0	0
300	+0.1	0
400	0	0
500	−0.1	+0.1
600	−0.1	+0.2
800	−0.1	+0.35
1000	+0.15	+0.3
1200	+0.2	+0.4
1400	0	+0.1
1600	+0.1	0
1800	0	−0.1
2000	+0.1	−0.3
2200	+0.25	−0.3
2400	+0.4	−0.4
2600	+0.45	−0.4
2800	+0.4	−0.5
3000	+0.4	−0.3
3200	+0.45	−0.25
3400	+0.4	−0.2
3600	+0.3	−0.1
3800	−0.05	−0.3
4000	−0.5	−0.3
4200	−1.5	−0.7

(1) Envelope delay measured over passed frequency band.
(2) Phase shift at 3.6 mc frequency between blanking level and white level.

Attenuation-Frequency

Interexchange Channel L1 Coaxial Cable Loop New York–Washington–New York–Total Length 486 Miles

Frequency kc	Deviations db
10	0
100	0
500	+0.2
1000	+0.1
1500	−0.5
2000	+0.9
2200	+0.7
2300	+0.5
2400	+0.2
2500	−1.0
2600	−3.7
2700	−6.5

	Coaxial	Local Channels
Env. Delay (1) (Microsecs.)	±0.5	±0.15
2 mc Phase Shift (2) (Degrees)	0	*

Associated Local Channels A2 Video Facilities Total Length 8.65 Miles

Frequency kc	Deviations db From NBC	Deviations db To NBC
5	+0.3	−0.5
10	0.0	0
25	0	−0.1
50	+0.15	−0.2
75	+0.1	−0.2
100	0	−0.25
150	−0.15	−0.35
200	−0.25	−0.2
250	−0.2	0
300	−0.15	0
400	−0.3	−0.05
500	−0.2	−0.25
600	−0.15	−0.4
800	0	−0.4
1000	0	−0.3
1200	+0.1	−0.2
1400	−0.125	−0.1
1600	−0.125	−0.1
1800	−0.2	−0.1
2000	−0.4	−0.15
2200	−0.35	−0.2
2400	−0.4	−0.1
2600	−0.3	−0.2
2800	−0.325	−0.15
3000	−0.4	−0.1
3200	−0.45	−0.15
3400	−0.35	−0.05
3600	−0.25	−0.15
3800	−0.3	−0.5
4000	−0.4	−0.75
4200	−0.85	−1.5

(1) Envelope delay measured over passed frequency band.

(2) Phase shift of 2.4 mc frequendy between blanking level and white level.

* Not measured, but should be same as local channels used with radio.

The NTSC Monographs*

DONALD G. FINK†, FELLOW, I.R.E.

The following article is the last in a special series of introductory papers prepared for this issue by officials of the NTSC, the first four of which appear at the beginning of this issue. Its purpose is to acquaint the reader with the scope of the NTSC Monographs, which appear in the pages immediately following, and the work of Panel 12 in preparing them. To accomplish this the author, who is Chairman of Panel 12, skillfully selected a series of questions and answers which admirably serve to underline for the reader the significant points covered by each of these important contributions.—*The Administrative Editor.*

WHEN THE National Television System Committee was reorganized in 1951, following the recommendations of the Ad Hoc Committee, it was recognized that one of the major tasks of the NTSC was communication of its findings to the electronics industry in terms as simple as technical accuracy would allow. To meet this need Panel 12, designated "Color System Analysis," was formed to analyze and interpret the techniques developed by the other panels, and to prepare tutorial papers for distribution to the 315 engineers actually engaged in NTSC activities, the FCC and its staff, and others on the NTSC mailing lists.

* Decimal classification: R583. Original manuscript received by the Institute October 3, 1953.
† Chairman, NTSC Panel 12; Philco Corp., Philadelphia, Pa.

Shortly after the Panel produced its first monographs, Dr. Alfred N. Goldsmith pointed out that wider distribution of such tutorial material was appropriate. He offered the pages of the PROCEEDINGS OF THE I.R.E. for this purpose; the offer was accepted by the NTSC and thereafter the documents were prepared with the understanding that they would be published to the membership of the Institute. In fulfillment of this plan, the present issue of the PROCEEDINGS contains the full text of all the Panel 12 documents except the first, the substance of which has been included in material already published in these pages.[1] The documents include a brief nontechnical description of the proposed NTSC standards and 14 technical monographs, totaling 52,000 words and 110 illustrations.

The initial membership of the Panel was drawn from six organizations active in color television research. As was the case in all NTSC groups, membership was open to any qualified engineer who desired to participate. However, when it was announced that the panel members and alternates would do most of the writing themselves, the membership stabilized abruptly at nine members, six alternates, and one observer. The NTSC had only one Panel (Panel 19) smaller than this; it had the onerous duty of preparing working definitions and symbols.

The work of Panel 12 extended over a period of two years. During that time 15 meetings were held during which the progress of the NTSC work was reviewed, subjects deserving monographic treatment were selected and authors assigned, the monographs themselves read, discussed, revised, and finally approved for transmittal to the NTSC. Three of the monographs were assigned to authors outside the Panel, since the detailed treatment of the subject matter lay outside the immediate experience of the panel members. Throughout the work of the Panel, the Chairman of Panel 19 served as an observer and arranged to have all the monographs reviewed for conformity with the NTSC working definitions. Extensive revision of the first seven monographs was needed when the NTSC Signal Specifications were revised early in 1953.

TECHNICAL AREAS COVERED

The technical areas covered by the monographs fall in two broad divisions: (1) the principles of colorimetry and photometry as applied to the generation and utilization of the NTSC color signal, and (2) the structure of the color signal in the frequency and time domains, including the errors caused by bandwidth limitations, interference and noise. The first group attempts to answer the broad question: "How well (how free from error) does the NTSC signal represent the content of the televised scene, without regard to transmission limitations?" The second group examines such matters as the effect of the transmitter amplitude and phase characteristics, the relative effect of interference on the luminance and chrominance signals, and the effect of noise on the stability of color synchronization.

It should not be inferred that the Panel operated from the start by reference to an orderly grouping of the subject matter. Rather, the panel members took up topics which seemed important because they were imperfectly understood by the NTSC membership at large or because (as in the case of the paper on phase accuracy of color synchronization) a theoretical confirmation of experimental results was needed. Only in hindsight do the monographs fall into an orderly pattern.

Seven of the monographs deal directly with the colorimetric and photometric bases of the NTSC signal: three linking the CIE system of color specification with the electrical signals, one on the choice of the chrominance axes, one on the proportioning of the signal to secure constant-luminance operation, another giving the explicit mathematical formulation of these techniques, and one on gamma correction.

The remaining seven monographs, dealing with signal transmission and its errors, cover the choice of the chrominance subcarrier frequency, the side-band-frequency interleaving principle, quadrature cross talk arising from the chrominance bandwidth limitations, a method of narrow-band transmission of the NTSC signal, the basis of the time-delay specifications, the effect of transmitter phase and amplitude characteristics on the radiated modulation envelope, and phase-synchronization accuracy.

Some idea of the scope covered by the Panel 12 documents may be gathered from the following list of questions, the answers to which may be found by study of the respective monographs:

Question: If at some future time it proves desirable to construct color receivers using four or more primary colors, in the interest of covering the widest possible gamut of colors in the reproduced image, would any changes in the NTSC signal be necessary to accommodate such receivers?

Answer: No, the three-color quantities present in the NTSC signal are sufficient *in principle* to operate a receiver having any number of primary colors (Bingley, Monograph 1).[2]

Question: If the blue color-difference signal is interrupted by the failure of a video-amplifier tube carrying this signal, but the red color-difference signal is present, what colors will appear on the picture tube, assuming the receiver is otherwise operating correctly?

Answer: The image will be reproduced in cyans and purples of various saturations (Bingley, Monograph 6, Fig. 1).[3]

[1] F. J. Bingley, "Colorimetry in color television," PROC. I.R.E., vol. 41, pp. 838–850; July, 1953.

[2] *Ibid.*

[3] PROC. I.R.E., pp. 48–51, this issue.

Question: What is the effect of gamma correction on the shape of the chrominance axes?

Answer: The axes (straight lines with linear transmission) become curved when gamma correction is employed; the curved lines pass through the white point and, in vicinity of the white point, have same slope as straight-line axes (Bingley, Monograph 8).[4]

Question: What is the effect on the reproduced image of the frequency content from 0.6 to 1.3 mc in the I-channel chrominance signal?

Answer: If these frequencies are utilized in the receiver, picture details corresponding in size to this frequency range are reproduced in two colors, orange and cyan, whereas larger details are reproduced in full color (Brown, Monograph 14).[5]

Question: What is the most important benefit of the constant-luminance method of color transmission?

Answer: The effect of spurious components, such as noise and interference, is rendered less visible if the effect of these components is transferred as much as possible from the luminance signal to the chrominance signals (Bailey, Monograph 11).[6]

Question: In how many different ways can the complete color signal be represented symbolically?

Answer: There are an infinite number of ways of expressing the basic equation. There are four ways of tutorial interest: in terms of red and blue color-difference signals, in terms of the three primary signals, in terms of red, blue, and green color-difference signals, and in terms of symmetrical components (Brown, Monograph 4a.)[7]

Question: What is the principal difference between the several proposed methods of gamma correction, so far as the reproduced image is concerned?

Answer: The proposed methods operate identically in the vicinity of the white point; the difference appears in the relative luminances of highly saturated colors (Bingley, Monograph 12).[8]

Question: Why is the line-scanning frequency in the NTSC specification 15,734+ cps rather than 15,750 cps as in the present monochrome standard?

Answer: To maintain the sound-picture intercarrier spacing at the exact value of 4.5 mc for which existing monochrome intercarrier receivers are designed, while keeping the chrominance subcarrier side-band in offset relationship to sound and picture carriers, it was necessary to select the scanning frequencies 0.1 per cent lower than the monochrome values (Abrahams, Monograph 9).[9]

Question: How are the luminance and chrominance side-bands put into interleaved relationship?

Answer: By choosing the chrominance subcarrier frequency equal to an odd multiple of one-half the line-scanning frequency (Abrahams, Monograph 3).[10]

Question: How is cross talk between the two chrominance signals minimized in the NTSC signal?

Answer: By appropriate choice of the chrominance axes and the bandwidths assigned to each, and by transmitting at least one of the chrominance signals by *double side-band* modulation of the chrominance subcarrier (Bailey and Hirsch, Monograph 2a.)[11]

Question: How can the complete color signal, including the chrominance subcarrier (frequency 3.579+ mc), be transmitted over a coaxial cable limited to a maximum frequency of 2.7 mc?

Answer: By heterodyning the subcarrier and its adjacent side-bands to a lower frequency, within the cable passband, before transmission, and heterodyning them back to the standard values after transmission, and by cutting off the luminance signal at a frequency low enough to avoid interference with the subcarrier and its side-bands while the signal is on the cable (Reddeck, Monograph 5a.)[12]

Question: On what basis was the transmitter time-delay specification selected?

Answer: To compensate for the measured phase response of typical monochrome receivers, which have been found to display a high degree of uniformity in this respect (Palmer, Monograph 10).[13]

Question: In what way does the radiated color-sync burst (modulation envelope) differ most noticeably from the corresponding wave form applied to the transmitter modulator?

Answer: The percentage peak-to-peak amplitude of the burst as radiated is one-half that of the modulating wave form, since the burst frequency is transmitted by vestigial sideband (Fredendall and Morrison, Monograph 13).[14]

Question: How much random noise may be present in the color synchronizing signal, in a correctly designed receiver, before the reproduced hues are noticeably affected by loss of synchronism?

Answer: The rms value of the noise may be as great as the peak value of the synchronizing signal (unity signal/noise ratio), if full advantage is taken of the information present in the color-burst signal (Richman, Monograph 7).[15]

It is hoped that these papers, written by outstandingly qualified specialists aiming to *teach* as well as to put down the facts, will be of great value not only to the engineers whose task it is to translate the NTSC specifications into a nationwide service, but also to the teachers who must train future engineers in the new technology of compatible color television.

[4] Proc. I.R.E., pp. 51–57, this issue.
[5] Proc. I.R.E., pp. 58–59, this issue.
[6] Proc. I.R.E., pp. 60–66, this issue.
[7] Proc. I.R.E., pp. 66–71, this issue.
[8] Proc. I.R.E., pp. 71–78, this issue.
[9] Proc. I.R.E., pp. 79–80, this issue.
[10] Proc. I.R.E., pp. 81–83, this issue.
[11] Proc. I.R.E., pp. 84–90, this issue.
[12] Proc. I.R.E., pp. 90–91, this issue.
[13] Proc. I.R.E., pp. 92–95, this issue.
[14] Proc. I.R.E., pp. 95–105, this issue.
[15] Proc. I.R.E., pp. 106–133, this issue.

The NTSC Color Television Standards*

The general principles by which a color television system operates under NTSC standards have been clearly described in non-technical language in the report of Panel 12 of the NTSC. This description is reprinted here in the belief that the non-specialist reader will find it a valuable introduction to the NTSC Technical Monographs which follow.—*The Editor*

Introduction

THE NTSC COLOR television standards are designed to meet two basic requirements: (1) to provide the best color television service possible within the standard 6 mc television channel, and (2) to provide a color signal which will produce a high quality monochrome image on existing black-and-white receivers, without requiring any change whatever in such receivers.

These aims are achieved by transmitting two signals, one identical in all essential respects to the black-and-white television signal, the other (the "chromatic signal") carrying two types of color information which jointly represent the chromatic values of the scene. By using multiplex techniques these signals are sent simultaneously over the channel of the television station.

When a conventional black-and-white receiver is tuned to transmissions conforming to the NTSC color standards the receiver responds fully to the first signal (the "brightness signal") and recreates from it an image in black-and-white having a quality equal (or superior) to that provided by present black-and-white standards. Because of the nature of the chromatic signal, no normally perceptible effect is produced by it in the black-and-white image on such a receiver.

The color receiver, however, responds to both signals, and the chromatic signal is then used specifically to recreate in the image the color values lacking in the brightness signal. Moreover, when the chromatic signal is absent, as when the color receiver is tuned to a black-and-white transmission, the receiver produces without any change or adjustment, an image in black-and-white.

In this manner, compatibility is achieved between color broadcasts and the black-and-white broadcasts. The black-and-white receiver produces black-and-white images from either type of broadcast and the color receiver produces images, according to the type of broadcast, in color or in black-and-white.

Basis of the NTSC Color Standards

The technical basis of the NTSC color standards lies in the science of color measurement (colorimetry). Those concerned with the matching of colors, for example those engaged in color printing and color photography, have for many years recognized that the color of an object can be identified by three quantities representative of its *brightness*, its *hue* and its *saturation*. The brightness is a measure of the lightness or darkness of a color; the hue specifies whether the color is red, or blue, or yellow, for example; and saturation is a measure of the mixture of this hue with white light. The hue and the saturation values together represent the chromatic values of the color.

When a scene is photographed with black-and-white film, the film responds only to brightnesses in the scene, while the chromatic values of the colors are lost. When the same scene is photographed with color film, three individual images are recorded, one in each of the three primary colors. By keeping the brightness of the three primary colors in proper proportion, the chromatic values (hues and saturations) of the colors are preserved and can be made available in the color print or transparency. Photographic technicians have, in fact, produced experimental photographs which are somewhat analogous to the two signals of the NTSC color standards, one photograph (in black-and-white) showing only the brightness values on the scene, and another (in color but having equal brightness at every point) indicating only the chromatic values present. The NTSC color standards define an electrical process for achieving the same result. The essential elements of the system are outlined in the following paragraphs.

The Color Camera and Tricolor Picture Tube

The apparatus suitable for the NTSC standards is conveniently divided into two more or less independent groups, the *terminal equipment* (camera at the transmitter and picture tube at the receiver) and the *transmission equipment* which carries the television signal from one terminal to the other.

A color camera suitable for the NTSC color standards may incorporate three image-orthicon camera tubes, similar to the camera tubes used in black-and-white broadcasting. Each of the tubes is fitted with a color filter (transparent colored glass), in such a way that one camera tube receives an image in red light, the second an image in green light and the third in blue light. In this manner the color values of the scene are analyzed into three primary colors. The three camera tubes are so mounted that they view the scene from the same vantage point. Therefore, the three primary color images have the same geometric form, but differ in the color of the light. In the camera tubes, each image is converted into a corresponding electrical signal.

* Decimal classification: R583×R020. Reprinted by permission of the National Television System Committee from "Color System Analysis," Report of NTSC, Panel 12.

The color camera thus produces three signals, each representing the same scene, but differing according to the colors present in the scene. For example, in representing the white and gray parts of the scene, all three signals are active (since white or gray light is produced by a combination of all three primary colors). In red parts of the scene, the red primary signal is predominant; in yellow parts, both red and green signals are strong (since yellow light is produced by a combination of red and green lights), and so on.

The opposite terminal of the color television system is the picture reproducer. To it are fed three signals similar to those generated by the camera, producing corresponding images in red, green and blue light. A typical picture reproducer suitable for the NTSC color standards is the tricolor picture tube. In one form of tricolor tube the viewing screen consists of several hundred thousand individual phosphor dots of three different types. One set of dots produces red light, a second set, green light, and the third, blue light. The dots are uniformly interspersed on the viewing screen, so that dots of different color are adjacent, but do not overlap. This arrangement of colored dots is similar to that used in color printing.

To excite the phosphor dots, three electron beams are formed at the opposite end of the tube. The internal structure of the picture tube is so arranged that one electron beam is constrained to fall only on the red dots, the second beam only on the green dots, and the third only on the blue dots.

To recreate the image in full color, the three electron beams are produced simultaneously, forming three primary-color images consisting of dots so interspersed that the images occupy the same space on the viewing screen. The dot structure is so fine that it is not perceptible as such at normal viewing distances. Consequently the three images appear to be superimposed and the primary colors combine to reproduce the image in full color.

The three electron beams move ("scan") over the viewing screen in the same manner as the corresponding electron beams in the camera tubes of the color camera previously described. Thus, if the camera tube viewing the scene through the red filter is caused to control the beam in the tricolor tube which excites the red dots, the red colors in the image correspond to the red colors in the scene. A similar connection is provided between the blue camera tube and the blue dots, and between the green camera tube and green dots.

In brief, the three camera tubes generate three signals which, transmitted to the picture tube, recreate three corresponding primary-color images, superimposed on the viewing screen.

The Transmission Process—Signal Transformation

From the foregoing, it would appear that the transmission system connecting camera and picture tube should carry three signals representing the red, green, and blue primary-color values in the scene to be reproduced. But this simple one-to-one correspondence between images and signals has two important disadvantages: First, no one of these three signals is ideally suited to the operation of black-and-white receivers; a preferable signal arrangement involves a signal (the brightness signal previously mentioned) particularly designed to operate black-and-white receivers.

Second, and more important, the transmission of these three signals does not make the most efficient use of a television channel. The characteristics of human vision are such that, to use the channel most efficiently, the three signals should be transmitted in a preferential way, so that one signal (the brightness signal) is accorded the major portion of the width of the channel, while the other signals (which together represent chromatic values) are given less channel width.

The transformation from the primary-color signals produced by the color camera to the preferentially-treated brightness and chromatic signals is readily performed in simple electronic circuits. If the primary-color signals are fed to such a circuit a signal representative of brightness, and a pair of signals representing the chromatic values are produced. At the color receiver a similar circuit transforms the brightness and chromatic signal into the primary-color signals suitable for controlling the three electron beams in the tricolor picture tube.

Simultaneous Transmission of Brightness and Chromaticity Signals

The remaining problem is the simultaneous transmission of the brightness signal and the chromatic signal on the same channel without mutual interference. This technique can be explained briefly by reference to the method of transmitting a television image by means of radio. All radio transmissions involve a high-frequency wave known as the "carrier" which is "modulated" (caused to vary) in accordance to the program or other information to be transmitted. In amplitude modulation (AM) the power of the carrier wave is varied; in frequency modulation (FM) the frequency of the wave changes. In addition to these well known methods of modulation, a third may be used, known as phase modulation (PM). Phase modulation and frequency modulation are intimately related: one may readily be derived from the other.

In the NTSC color standards the chromatic signal modulates a so-called "color carrier." The pair of signals previously mentioned as jointly representing the chromatic values are applied together to the color carrier to modulate it. The two signals are so applied to the color carrier that the carrier is modulated in two ways, in amplitude and in phase. By thus modulating the color carrier in two ways simultaneously, two signals representing the chromatic values can be carried without loss of identity, provided that proper timing is maintained between the modulation process at the transmitter and

the inverse "demodulation" process at the receiver. This latter requirement is met by sending to the receiver, along with the television synchronizing pulses, a timing signal known as the color-phase signal. This signal causes the receiver chromatic signal circuits to operate in synchronism with those at the transmitter.

The brightness signal is transmitted in a manner exactly like that used in transmitting an image over a black-and-white transmitter. Consequently the quality associated with the brightness values in the received color image is at least equal to that of the black-and-white system and, for the same reason, reception of the color signal on black-and-white receivers is of high quality.

It then remains to arrange the chromatic signal and the brightness signal so that they utilize the channel assigned to the transmitter without undue interference. This problem is simplified by the fact that, as a result of the scanning process used in dissecting and reassembling the image, the brightness signal components are concentrated in uniformly spaced intervals across the channel. The chromatic signal is concentrated in a similar fashion, since it arises from the same scanning process.

It is feasible to shift the concentrations in the spectrum of the chromatic signal so that they fall between those of the brightness signal spectrum. This is accomplished by choosing the frequency of the color carrier as an odd multiple of one-half of the line frequency. In this manner, the whole of the spectrum assigned to the picture transmission is more completely occupied, and the two sets of signals are transmitted simultaneously without one interfering unduly with the other. That this is so is due to the fact, that with the particular choice of carrier frequency, the unwanted signal received with a certain phase in one field will be received with the opposite phase in a succeeding field, 1/30 of a second later.

Another factor which eliminates interference is inherent in the transmission of the brightness and chromatic signals as separate entities. Whenever a substantial portion of the televised scene appears in shades of gray or white, as previously noted, all three primary colors are active in the camera and picture tube. But in transforming the primary-color signals to brightness and chromatic signals, only one signal, the brightness signal, appears from such gray and white portions of the scene. Since the chromatic signal is then absent, there is no opportunity for interference to exist in such portions of the scene.

The over-all result is that the NTSC color television standards are capable of providing a high quality color picture with definition equal to that of present black-and-white pictures, and of producing a higher quality monochrome image on existing black-and-white receivers, without requiring any change whatever in such receivers.

Colorimetry in Color Television—Part II*

FRANK J. BINGLEY†, FELLOW, IRE

Summary—**This paper considers the modifications required to equations previously derived, when the television system is adjusted to normalize at an arbitrary chromaticity.**

Color maps for a television system with arbitrary normalizing chromaticities are shown in illustration of the equations.

THIS PAPER may be regarded as a continuation of previous papers on the subject of colorimetry in television.[1] The recent publications of specifications for a color television signal by the NTSC provides an opportunity for illustration.

The NTSC signal specifications provide that the color carrier shall vanish for an input chromaticity corresponding to illuminant C. It is interesting to examine how the fundamental color equations previously deduced, are modified to conform to normalization at chromaticities other than illuminant E or equal energy white.

The fundamental color equations derived previously are recapitulated below:

$$T_R = \alpha_1 X + \beta_1 Y + \gamma_1 Z$$
$$T_G = \alpha_2 X + \beta_2 Y + \gamma_2 Z$$
$$T_B = \alpha_3 X + \beta_3 Y + \gamma_3 Z$$

where $T_R T_G$ and T_B are the total tristimulus values of the three reproducing primaries, and X, Y and Z are the tristimulus values of the reproduced color. The nine constants α, β, γ, etc. are functions of the chromaticity co-ordinates of the reproducing primaries; their values in terms of the primary co-ordinates have been given previously, but are restated below for completeness

$$2\Delta\alpha_1 = y_G(1 - x_B) - y_B(1 - x_G)$$
$$2\Delta\alpha_2 = y_B(1 - x_R) - y_R(1 - x_B)$$
$$2\Delta\alpha_3 = y_R(1 - x_G) - y_G(1 - x_R)$$
$$2\Delta\beta_1 = x_B(1 - y_G) - x_G(1 - y_B)$$
$$2\Delta\beta_2 = x_R(1 - y_B) - x_B(1 - y_R)$$
$$2\Delta\beta_3 = x_G(1 - y_R) - x_R(1 - y_G)$$

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[1] For Part I of this series, see Proc. I.R.E., vol. 41, pp. 838–851; July, 1953.

$$2\Delta\gamma_1 = x_G y_B - x_B y_G$$
$$2\Delta\gamma_2 = x_B y_R - x_R y_B$$
$$2\Delta\gamma_3 = x_R y_G - x_G y_R$$

where

$$2\Delta = \begin{vmatrix} x_R & x_G & x_B \\ y_R & y_G & y_B \\ 1 & 1 & 1 \end{vmatrix}$$

and where $x_R y_R$; $x_G y_G$; and $x_B y_B$ are the chromaticity co-ordinates of the red, green and blue reproducing primaries respectively.

The fundamental equations may be rearranged as follows:

$$T_R = (f\alpha_1 + \beta_1 + g\gamma_1)Y + \alpha_1(X - fY) + \gamma_1(Z - gY)$$
$$T_G = (f\alpha_2 + \beta_2 + g\gamma_2)Y + \alpha_2(X - fY) + \gamma_2(Z - gY)$$
$$T_B = (f\alpha_3 + \beta_3 + g\gamma_3)Y + \alpha_3(X - fY) + \gamma_3(Z - gY).$$

This is purely a mathematical identity with the previous equations, as multiplying and collecting terms will show.

The purpose of this rearrangement is to separate the equations into luminance and color difference components. The color differences $X-fY$ and $Z-gY$ may be made to vanish at any desire chromaticity. For illuminant E, f and g would be unity; for illuminant C they would be almost unity. The chromaticity at which the color differences $X-fY$ and $Z-gY$ vanish will be referred to as the "normalizing color." By suitable choice of the normalizing constants f and g, any desired normalizing chromaticity may be selected.

Colorimetric quantities which are equal at the normalizing chromaticity are

$$R = \frac{T_R}{f\alpha_1 + \beta_1 + g\gamma_1} = Y + p_1'(X - fY) + q_1'(Z - gY)$$

$$G = \frac{T_G}{f\alpha_2 + \beta_2 + g\gamma_2} = Y + p_2'(X - fY) + q_2'(Z - gY)$$

$$B = \frac{T_B}{f\alpha_3 + \beta_3 + g\gamma_3} = Y + p_3'(X - fY) + q_3'(Z - gY)$$

where

$$p_1' = \frac{\alpha_1}{f\alpha_1 + \beta_1 + g\gamma_1} \qquad q_1' = \frac{\gamma_1}{f\alpha_1 + \beta_1 + g\gamma_1}$$

$$p_2' = \frac{\alpha_2}{f\alpha_2 + \beta_2 + g\gamma_2} \qquad q_2' = \frac{\gamma_2}{f\alpha_2 + \beta_2 + g\gamma_2}$$

$$p_3' = \frac{\alpha_3}{f\alpha_3 + \beta_3 + g\gamma_3} \qquad q_3' = \frac{\gamma_3}{f\alpha_3 + \beta_3 + g\gamma_3}.$$

These equations are analogous to equations previously deduced for illuminant E normalization, and reduce the previous equations on putting $f=g=1$. The quantities R, G and B are directly related to the channel voltages widely referred to as "R," "G" and "B." They may be used interchangeably with the corresponding voltage terms.

All of the equations given in the previous papers can be rewritten into the broader form permitting any normalizing chromaticity to be specified. For example, the primary luminance equations become:

$$Y_R = y_R T_R = y_R(f\alpha_1 + \beta_1 + g\gamma_1)R = sR$$
$$Y_G = y_G T_G = y_G(f\alpha_2 + \beta_2 + g\gamma_2)G = tG$$
$$Y_B = y_B T_B = y_B(f\alpha_3 + \beta_3 + g\gamma_3)B = uB$$

where s, t and u may be called the red, green and blue luminance coefficients respectively. Since at the normalizing chromaticity $R=G=B$, s, t and u represent the relative luminance contributions of the three primaries when reproducing the normalizing chromaticity.

It is instructive to inquire concerning the control of luminance in a system with arbitrary normalizing chromaticity. An important question to be answered is, do the color difference values control luminance? This may be discussed as follows.

The fundamental equations may be rewritten in terms of luminance by using the relations $Y_R = y_R T_R$, $Y_G = y_G T_G$ and $Y_B = y_B T_B$. Thus there is obtained

$$Y_R = y_R T_R = y_R(f\alpha_1 + \beta_1 + g\gamma_1)Y + \alpha_1 y_R(X - fY) + \gamma_1 y_R(Z - gY)$$
$$Y_G = y_G T_G = y_G(f\alpha_2 + \beta_2 + g\gamma_2)Y + \alpha_2 y_G(X - fY) + \gamma_2 y_G(Z - gY)$$
$$Y_B = y_B T_B = y_B(f\alpha_3 + \beta_3 + g\gamma_3)Y + \alpha_3 y_B(X - fY) + \gamma_3 y_B(Z - gY).$$

If these three equations are added, and if use is made of the identities

$$\alpha_1 y_R + \alpha_2 y_G + \alpha_3 y_B = 0$$
$$\beta_1 y_R + \beta_2 y_G + \beta_3 y_B = 1$$
$$\gamma_1 y_R + \gamma_2 y_G + \gamma_3 y_B = 0$$

it will be found that the sum of the luminance equations reduces to

$$Y_R + Y_G + Y_B = Y$$

the coefficients of $X-fY$ and of $Z-gY$ having vanished in view of the identities above.

It can be seen that $X-fY$ and $Z-gY$ do not control luminance. This is true no matter what the normalizing chromaticity is. The broad basis for this fact resides in the transmission of luminance information as a complete package. There is then needed no other element to control luminance if the transmission is to have colorimetric fidelity. It follows that subsequent electrical interconnections at the receiver must be so made as to avoid control of luminance by the color difference values.

The values of the constants f and g for illuminant C can be calculated simply as follows:

For illuminant C

$$x_c = .310$$
$$y_c = .316$$

thus

$$z_c = .374.$$

If $X-fY=0$ at illuminant C, then must $x_c-fY_c=0$ so that

$$f = \frac{x_c}{y_c} = \frac{.310}{.316} = .98.$$

Similarly, if $Z-gY=0$ at illuminant C then must $Z_c-gY_c=0$ so that

$$g = \frac{z_c}{y_c} = \frac{.374}{.316} = 1.18.$$

These, then, are the values which f and g must have for the NTSC signal, for which the normalizing chromaticity is specified to be illuminant C.

A table showing numerical values for the constants in the fundamental equations for the NTSC signal is given as Table I below.

TABLE I

NUMERICAL VALUES OF CONSTANTS FOR NTSC SIGNAL

Primary	x	y	α	β	γ
Red	.670	.330	1.7301	−.4823	−.2611
Green	.210	.710	−.8135	1.6517	−.0234
Blue	.140	.080	.0834	−.1694	1.2845

Primary	$f\alpha$	$g\gamma$	$f\alpha+\beta+g\gamma$	$y(f\alpha+\beta+g\gamma)$	p'	q'
Red	1.697	−.308	.907	.299	1.910	−.288
Green	−.796	−.028	.828	.587	−.956	−.028
Blue	.082	1.515	1.428	.114	.058	.898

In this table $\alpha\beta\gamma p'$ and q' will bear subscripts 1, 2 and 3 for red, green, and blue respectively.

The fundamental equations may be arranged in terms of color differences exclusively as follows:

$$R - Y = p_1'(X - fY) + q_1'(Z - gY)$$
$$G - Y = p_2'(X - fY) + q_2'(Z - gY)$$
$$B - Y = p_3'(X - fY) + q_3'(Z - gY).$$

This proves that, since $X-fY$ and $Z-gY$ do not control luminance, neither can $R-Y$, $G-Y$ nor $B-Y$. This is true no matter what normalizing chromaticity is chosen.

Some interesting color maps can be drawn for systems having an arbitrary normalizing chromaticity. Using the equation

$$R - Y = p_1'(X - fY) + q_1'(Z - gY)$$

it can be rearranged to show that

$$\frac{R-Y}{Y} = p_1'\left(\frac{x}{y} - f\right) + q_1'\left(\frac{1-x-y}{y} - q\right)$$

or

$$y\left[\frac{R-Y}{Y} + fp_1' + (1+g)q_1'\right] = x[p_1' - q_1'] + q_1'.$$

This is the equation of a straight line passing through the point

$$x = \frac{q_1'}{q_1' - p_1} \qquad y = 0$$

and having a slope given by

$$\tan\theta_1 = \frac{p_1' - q_1'}{\dfrac{R-Y}{Y} + fp_1' + (1+g)q_1'}.$$

These straight lines all pass through a fixed point on the x axis. This fixed point can be shown to be the intersection of the line joining the Green and Blue primaries, with the x axis. The slope is a function of the parameter $(R-Y)/Y$.

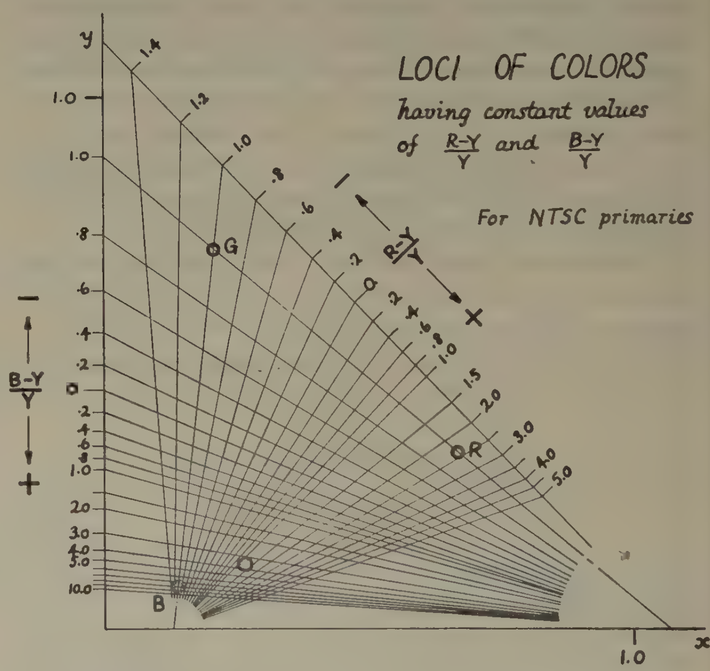

Fig. 1

Using the values of the constants for the NTSC signal given in the preceding table, a family of these straight lines for various values of $(R-Y)/Y$ may be plotted on the chromaticity diagram. A similar family for various values of $(G-Y)/Y$ may be plotted. A composite plot gives a voltage mapping of colors in the chromaticity diagram, and is shown in Fig. 1. This composite plot shows that a chromaticity can be represented by a pair of values of the quantities $(R-Y)/Y$ and $(G-Y)/Y$. In

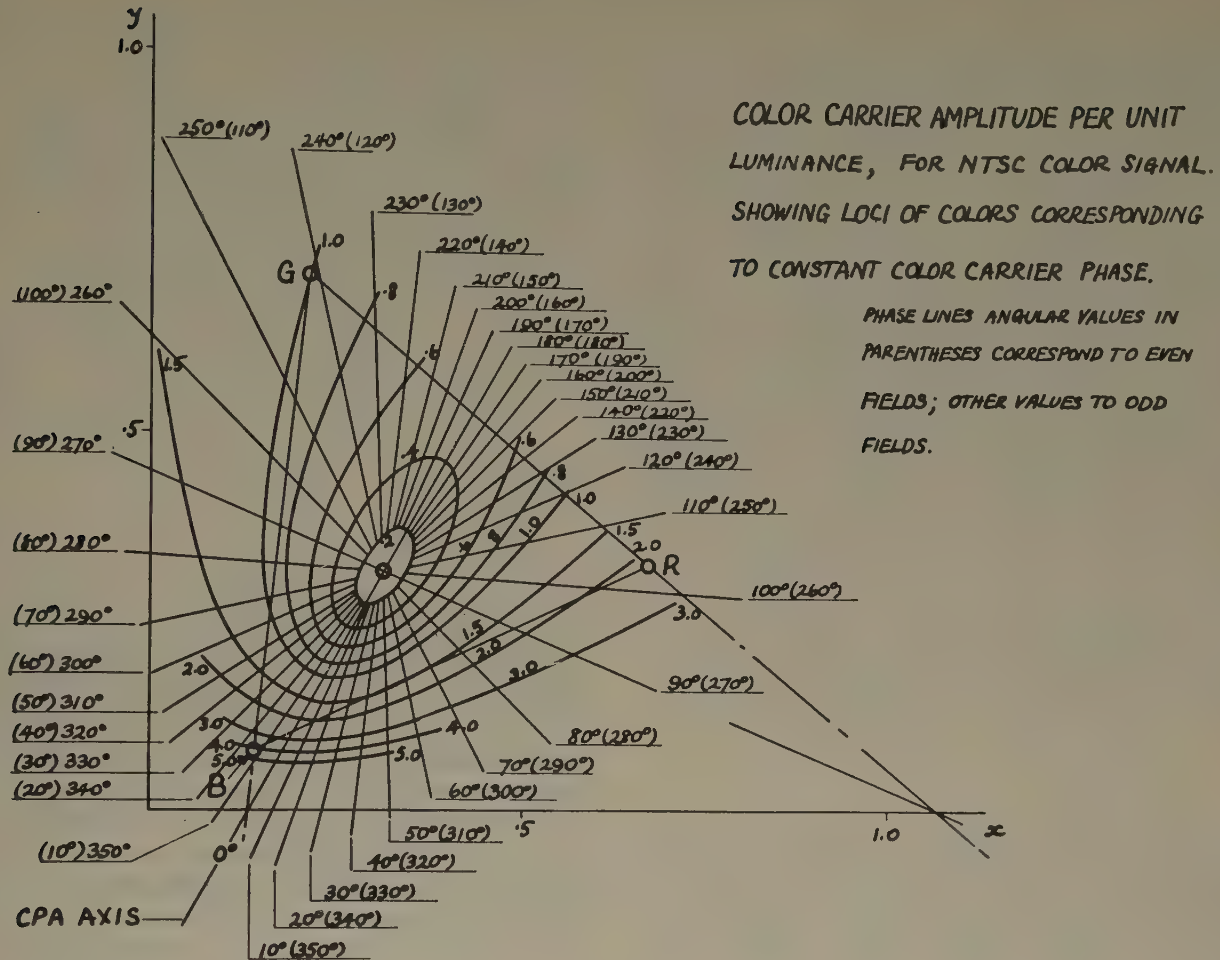

Fig. 2

using such a pair of values, the appropriate rays are selected and their intersection is located. This intersection gives the location of the corresponding color on the chromaticity diagram, from which the corresponding chromaticity co-ordinates may be read if desired.

Such a map can be transformed to show chromaticity co-ordinates in terms of color carrier amplitude per unit luminance, and color carrier phase. To do this requires a specification for the color carrier makeup in terms of the colorimetric quantities $R-Y$ and $G-Y$. The revised specifications proposed by NTSC (see document NTSC G-306) can be used in order to derive this map. This has been done, on the assumption of a linear system, and is presented as Fig. 2. It shows, on a chromaticity diagram, loci of constant color carrier amplitude per unit luminance; these loci form a family of ellipses. The figure also shows loci of constant color carrier phase; these are a family of straight lines passing through the normalizing chromaticity, which coincides with the zero subcarrier chromaticity at illuminant C in this case.

Colorimetry in Color Television—Part III*

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Summary—In this paper the NTSC encoding specifications are considered including the effect of gamma correction. Color carrier maps are shown for various proposals considered by NTSC. These maps include the effect of gamma correction. The path of a color transition is also discussed and illustrated.

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IN PREVIOUS PAPERS a number of colorimetric principles have been developed, based upon well established colorimetric practice. These principles have been in such a form as to be particularly applicable to television as a color reproducing system. This paper will give some specific applications in terms of systems presently under consideration by the National Television Systems Committee.

The fundamental equations which have been developed in preceding papers are:

$$R = Y + p_1'(X - fY) + q_1'(Z - gY) \qquad (1)$$
$$G = Y + p_2'(X - fY) + q_2'(Z - gY) \qquad (2)$$
$$B = Y + p_3'(X - fY) + q_3'(Z - gY) \qquad (3)$$

$$Y_R = y_R(f\alpha_1 + \beta_1 + g\gamma_1)R = sR \qquad (4)$$
$$Y_G = y_G(f\alpha_2 + \beta_2 + g\gamma_2)G = tG \qquad (5)$$
$$Y_B = y_B(f\alpha_3 + \beta_3 + g\gamma_3)B = uB \qquad (6)$$

$$Y = Y_R + Y_G + Y_B = sR + tG + uB \qquad (7)$$

where f and g are constants, and where

$$p_1' = \frac{\alpha_1}{f\alpha_1 + \beta_1 + g\gamma_1} \qquad q_1' = \frac{\gamma_1}{f\alpha_1 + \beta_1 + g\gamma_1}$$
$$p_2' = \frac{\alpha_2}{t\alpha_2 + \beta_2 + g\gamma_2} \qquad q_2' = \frac{\gamma_2}{f\alpha_2 + \beta_2 + g\gamma_2}$$
$$p_3' = \frac{\alpha_3}{f\alpha_3 + \beta_3 + g\gamma_3} \qquad q_3' = \frac{\gamma_3}{t\alpha_3 + \beta_3 + g\gamma_3}$$

and

$$s + t + u = 1.$$

These equations are expressed entirely in terms of colorimetric quantities and constants. The values of most of the constants are determined by the co-ordinates of the three primaries involved. A tabulation of the relations between the constants in the fundamental equations and the chromaticity co-ordinates of the primaries is shown in Fig. 1. The two remaining constants,

VALUES OF COEFFICIENTS

$$2\Delta\alpha_1 = y_G(1-x_B) - y_B(1-x_G)$$
$$2\Delta\alpha_2 = y_B(1-x_R) - y_R(1-x_B)$$
$$2\Delta\alpha_3 = y_R(1-x_G) - y_G(1-x_R)$$
$$2\Delta\beta_1 = x_B(1-y_G) - x_G(1-y_B)$$
$$2\Delta\beta_2 = x_R(1-y_B) - x_B(1-y_R)$$
$$2\Delta\beta_3 = x_G(1-y_R) - x_R(1-y_G)$$
$$2\Delta\gamma_1 = x_G y_B - x_B y_G$$
$$2\Delta\gamma_2 = x_B y_R - x_R y_B$$
$$2\Delta\gamma_3 = x_R y_G - x_G y_R$$

where

$$2\Delta = \begin{vmatrix} x_R & x_G & x_B \\ y_R & y_G & y_B \\ 1 & 1 & 1 \end{vmatrix}$$

and where

$x_R\, y_R$; $x_G\, y_G$; $x_B\, y_B$ are the coordinates of the Red Green and Blue receiver primaries respectively

Fig. 1

f and g, are determined by the chromaticity at which it is desired to make the quantities $X-fY$ and $Z-gY$ vanish. This chromaticity has previously been referred to as the normalizing chromaticity. The first three equations show three colorimetric quantities which are equal at the normalizing color, and whose values completely specify the color being transmitted by the system. The next three equations express the luminance contributed by each of the three primaries participating in the reproduction; while the final equation expresses the luminance of the reproduced color.

When a specific set of numerical values is given for a system, such as the NTSC specification, the constants in the fundamental equations take on definite numerical values. For the NTSC specification these numerical values are shown below, where the fundamental equations have been rewritten with the appropriate numerical values inserted for the NTSC specifications.

$$R = Y + 1.910(X - .98Y) - .288(Z - 1.18Y)$$
$$G = Y - .956(X - .98Y) - .028(Z - 1.18Y)$$
$$B = Y + .058(X - .98Y) + .898(Z - 1.18Y)$$

$$Y_R = .299R$$
$$Y_G = .587G$$
$$Y_B = .114B$$
$$Y = .299R + .587G + 114B$$

In order to transform colorimetric values which have been shown above into voltages suitable for transmission over the system, it is necessary to make up specified functions of these colorimetric quantities in terms of related electrical signals. This process has often been referred to as "encoding."

In the NTSC specification, the first operation in the "encoding" process is to transform the tristimulants[1] R, G and B into linearly related voltages. Such voltages will share all of the properties of the tristimulant from which each is derived. In particular, all three will be equal at the normalizing chromaticity, which NTSC has picked to be illuminant C.

NTSC has specified that the television signal shall be gamma corrected; that is to say the signals E_R, E_G, E_B shall be predistorted before transmission to compensate for an assumed non-linear characteristic of the color picture tube. It has been decided that a picture tube may be expected to have a power law characteristic, such that the tube output light is proportional to the 2.75 power of the input signal.[2] Thus the inverse power is used at the transmitter, in order that the over-all characteristic shall be linear.

The effect of this specification upon the color signals in various sections of the transmitter is shown by:

$$E_R = aR \qquad (8)$$
$$E_G = aG \qquad (9)$$
$$E_B = aB \qquad (10)$$

$$E_R' = E_R^{1/n} = a^{1/n}R^{1/n} = KR^{1/n} \qquad (11)$$
$$E_G' = E_G^{1/n} = a^{1/n}G^{1/n} = KG^{1/n} \qquad (12)$$
$$E_B' = E_B^{1/n} = a^{1/n}B^{1/n} = KB^{1/n} \qquad (13)$$
$$E_Y' = sE_R' + tE_G' + uE_B' \qquad (14)$$

[1] The term tristimulant is used in this paper to describe linear combinations of the CIE tristimulus values X Y and Z.

[2] Since this paper was written NTSC has changed the value of gamma recommended from 2.75 to 2.2.

$$E_R' - E_Y' = (1-s)E_R' - tE_G' - uE_B'$$
$$= KY^{1/n}\left\{(1-s)\left[\frac{R}{Y}\right]^{1/n} - t\left[\frac{G}{Y}\right]^{1/n} - u\left[\frac{B}{Y}\right]^{1/n}\right\} \quad (15)$$

$$E_B' - E_Y' = KY^{1/n}\left\{(1-u)\left[\frac{B}{Y}\right]^{1/n} - s\left[\frac{R}{Y}\right]^{1/n} - t\left[\frac{G}{Y}\right]^{1/n}\right\} \quad (16)$$

where for NTSC primaries

$$s = .299$$
$$t = .587$$
$$u = .114.$$

Equations (8), (9) and (10) show the three channel voltages as being proportional to R, G and B with a constant of proportionality "a" which is the same for all three signals. The next group of three (11), (12) and (13) shows the gamma corrected channel voltages, where the symbol "n" is used to indicate the gamma index. Equation (14) shows the monochrome signal as being made up of the sum of the products of the gamma corrected voltages by the appropriate luminance contribution coefficients. The final pair (15) and (16) show the two color difference signals which are subsequently modulated onto the color carrier.

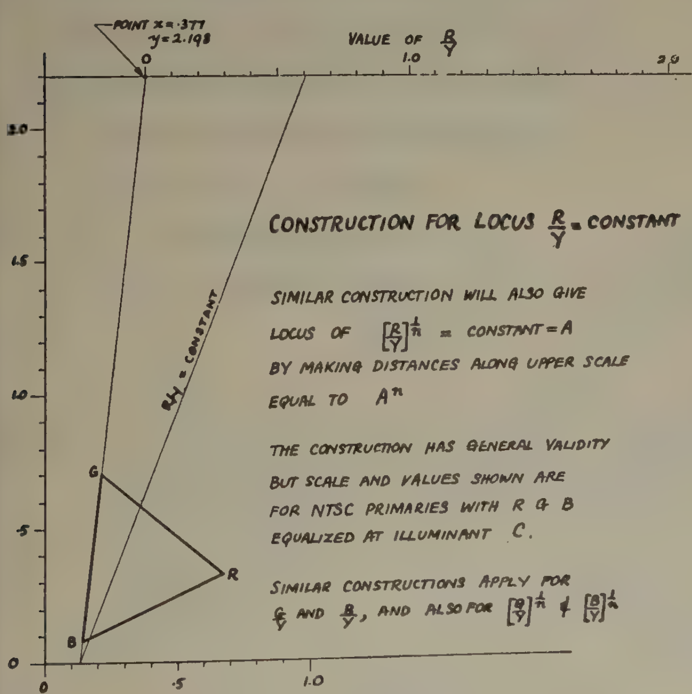


Fig. 2

It may be noted that the two color difference signals will vanish at the normalizing chromaticity, because, at that color $(R/Y)(G/Y)$ and B/Y are all unity, and further because $s+t+u$ is equal to 1.

Before proceeding with further discussion of color television systems, it is appropriate to take a look at Fig. 2. This shows an interesting construction for the locus of chromaticities for which the value of R/Y is a constant. The diagram has been drawn to scale for the NTSC primaries and shows these located at the points R, G and B. As has been shown previously, the locus of constant R/Y is a straight line passing through a fixed point of the x axis. An interesting property of this locus is further that its location is defined by its intercept upon the fixed line shown parallel to the X axis. This intercept, measured from the reference point shown at the intersection of the fixed line and the extension of the side BG of the primary triangle, bears a linear relation to the value of R/Y. A further interesting property of this locus is that it is also applicable to the gamma corrected case as is indicated on the diagram. Similar loci exist for G/Y and B/Y and their gamma corrected counterparts.

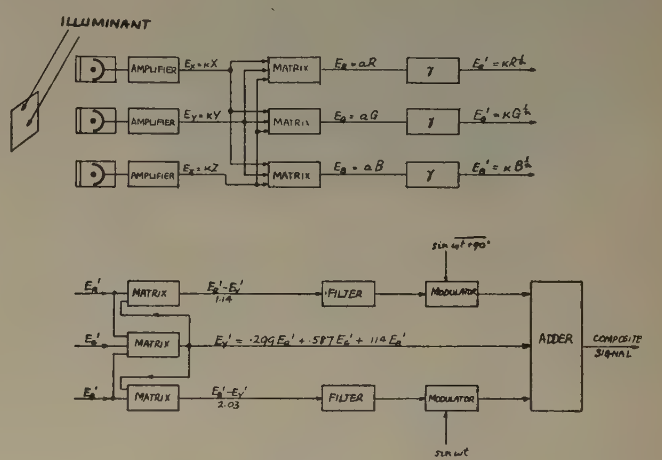


DIAGRAM OF NTSC SYSTEM

Fig. 3

Fig. 3, a diagram of the NTSC system illustrates signals occurring at various parts of the system, and the processes to which these signals are submitted. It is included to provide a basis for succeeding discussion.

The lines of constant $(R/Y)(G/Y)$ and B/Y, described above, can be used to construct chromaticity and color carrier maps. Earlier papers have shown such maps, and Fig. 4 is reproduced from a previous paper. It shows a chromaticity map constructed on a CIE diagram to relate chromaticity to the values of $(R-Y)/Y$ and $(B-Y)/Y$. These lines coincide with corresponding lines for R/Y and B/Y because $(R-Y)/Y=(R/Y)-1$ and $(B-Y)/Y=(B/Y)-1$, so that the corresponding values of R/Y and B/Y can be obtained for each of these families of lines by adding unity to the parameter values shown on each line. It should be noted that the quantities $(R-Y)/Y$ and $(B-Y)/Y$, and also R/Y and B/Y partake of the nature of chromaticities in that they are pure numbers defining only the location of a color point on the chromaticity diagram, while giving in themselves no information as to the quantity of the color involved (usually specified by luminance). They furnish useful specifications of chromaticity for color television purposes because they are so closely related to the color difference values actually transmitted.

A map showing normalized color carrier for the NTSC signal without gamma correction has also been shown previously. This map is reproduced as Fig. 5. In this diagram the co-ordinates are the chromaticity co-ordinates x and y. In this sense, it is a chromaticity diagram. The locations of the three NTSC primaries are shown at R, G and B. Each member of the family of elliptical curves represents the locus of various possible chromaticities which may be transmitted when the color carrier amplitude bears to the luminance the ratio indicated on the corresponding curve. A given curve is traced out as the color carrier phase is varied, while holding the ratio of color carrier amplitude to luminance constant. An alternative way of thinking about this is to regard both the color carrier amplitude and the luminance as being held constant, while the color carrier phase is altered; one of the family of elliptic curves will then be traced out by the reproduced chromaticities.

The straight lines on the diagram radiate from the point representing the chromaticity of illuminant C. Each represents the various possible chromaticities which may be transmitted as the ratio of color carrier amplitude to luminance is varied, while keeping the phase of the color carrier constant. The dual values on these rays represent the phases in odd and even fields respectively, when CPA is used.

It will be seen that Fig. 5 enables a chromaticity to be specified by two numbers, namely (1) the relative color carrier amplitude—that is, the ratio of color car-

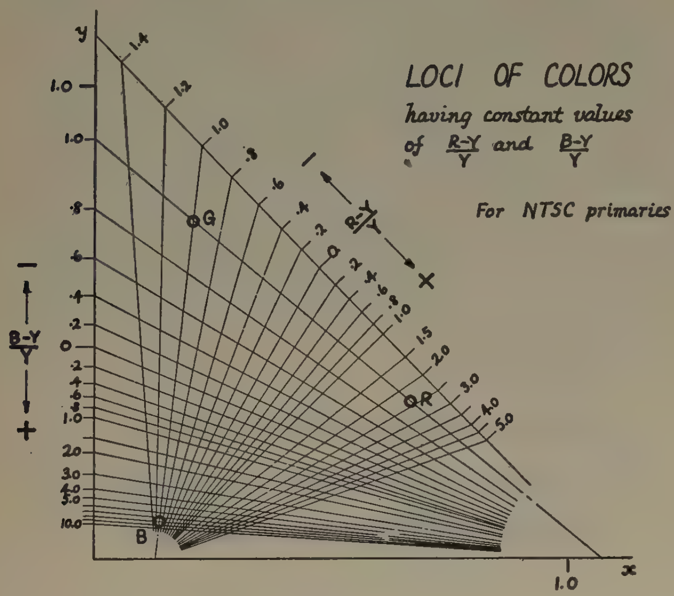


Fig. 4

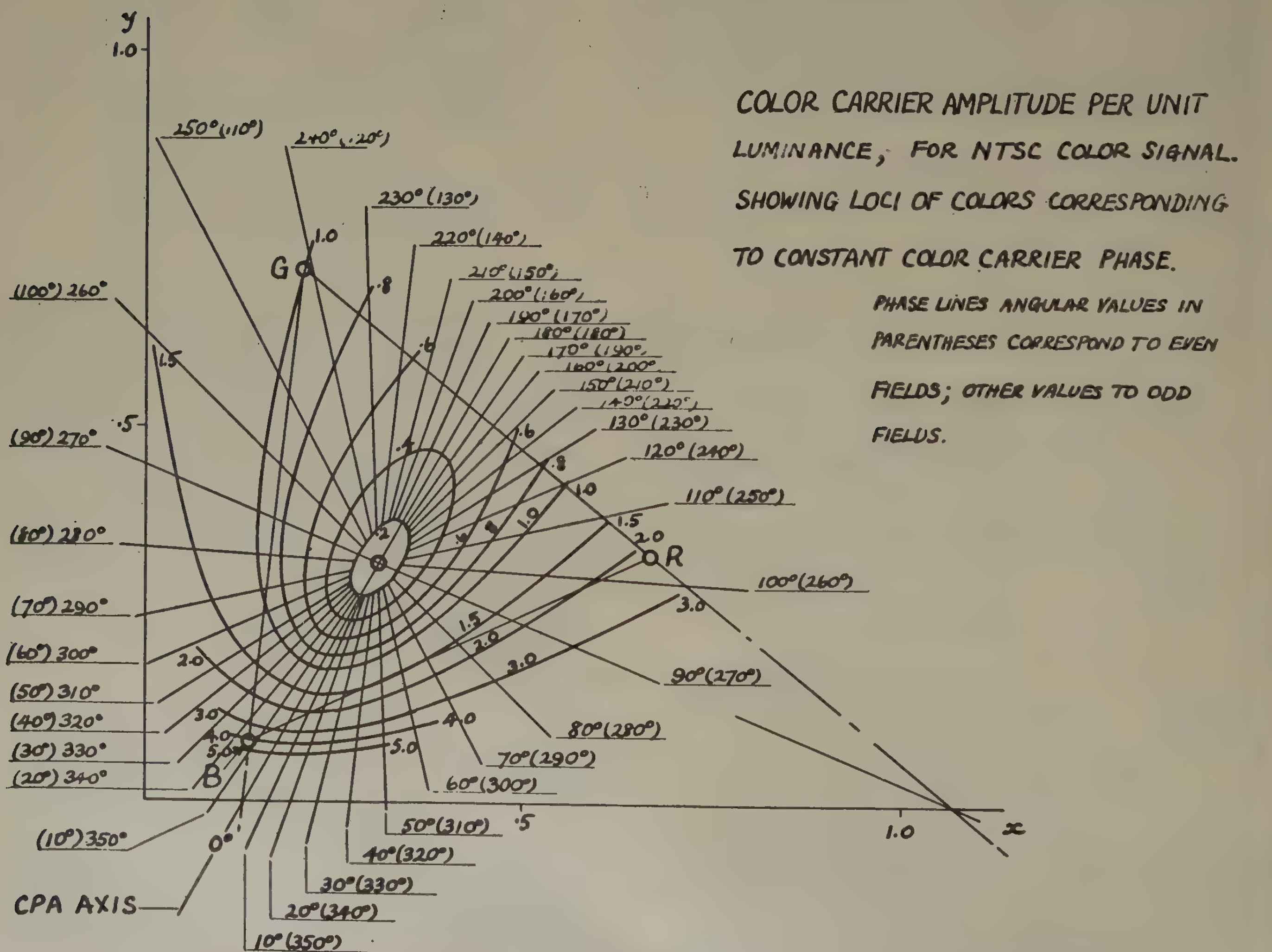


Fig. 5

rier amplitude to luminance or color carrier amplitude per unit luminance, and (2) the color carrier phase. These numbers are very directly related to the transmitted signal—but the diagram provides an immediate transformation to chromaticity by reading off the values of x and y.

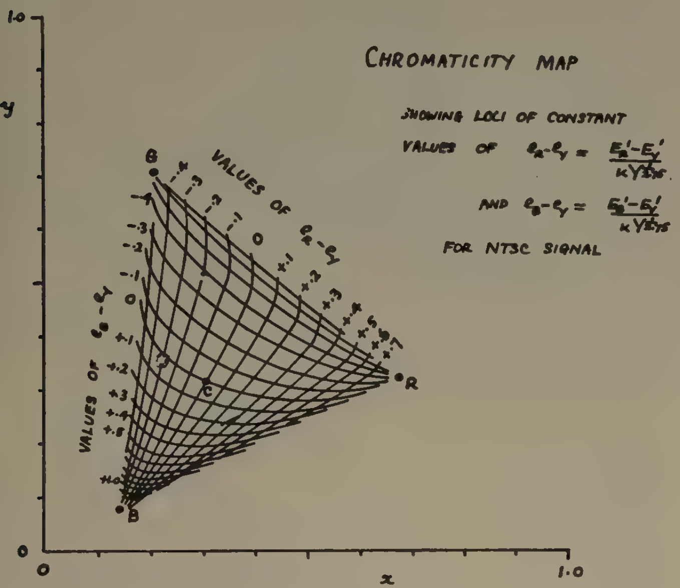


Fig. 6

By making use of the relations given in (15) and (16) above, it is possible to construct a chromaticity map for the gamma corrected signal. This is shown in Fig. 6. It will be seen that this new map bears similarities to the linear case in the general vicinity of illuminant C, but that the lines of which it is composed are now curved rather than straight and the departure from the linear

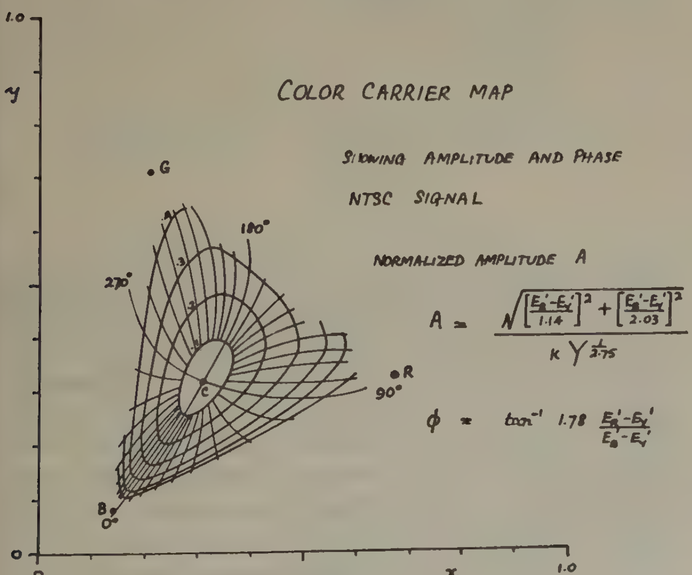


Fig. 7

case increases as more saturated chromaticities are transmitted. Fig. 7 shows a color carrier map for the NTSC signal derived from the preceding chromaticity map. It shows the loci of colors for which the normalized color carrier amplitude is constant, and also the paths of constant phase. These phase lines are shown for every 10 degrees of color carrier phase. Whereas these were straight lines in the linear case, they have now become curved.

A modified system which has been investigated by NTSC is shown in Fig. 8. It will be noticed that the system differs in that a new pair of signals are composed from the gamma corrected channel voltages. This pair is known as I and Q respectively, and each may be expressed as the sum of a pair of color differences of the type used in the original NTSC specification. There is a further difference between this signal and the original NTSC specification. In the original NTSC specification, the two color difference signals pass through identical filters having a bandwidth of about 1 mc before being fed to the modulator. In the modification, however, the signal referred to as I passes through a filter which has a wider band than the one which carries the Q signal. This modification system has been called the orange-cyan wide band system, for a reason which will appear later.

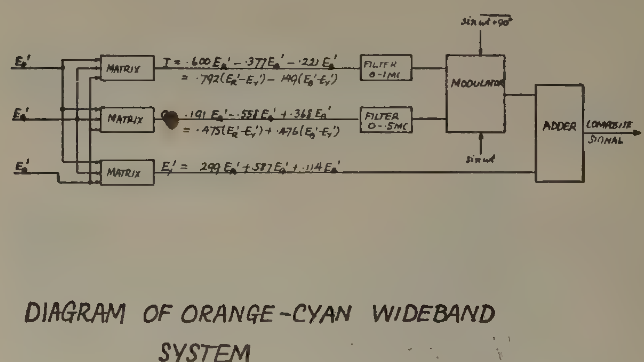


Fig. 8

A chromaticity map for I/Y and Q/Y is shown next, (Fig. 9). It will be seen that the locus of colors for which Q/Y is a constant is a straight line passing through illuminant C and through a fixed point on the X axis in the negative direction. Obviously this line passes through colors which are orange on the one hand and cyan on the other. This is the reason that the name orange-cyan has appeared in the name of this system. Since the Q signal is narrow banded, for frequencies above about $\frac{1}{2}$ mc the colors can only be delineated along this orange-cyan axis. These will be the colors described when successive values are given to I/Y, which is the only color difference component active in the frequency range above 500 kc. By techniques similar to those previously described it is possible to draw a chromaticity map for this system. This is shown in Fig. 10. Once again, it will be seen to match the linear map at and about illuminant C but to be composed of curved lines which cause more and more departure as the colors become more saturated. It should also be noticed that none of these lines has any existence outside of the triangle of primaries. This condition arises because, for example, R/Y is negative when it occurs to the left of the line

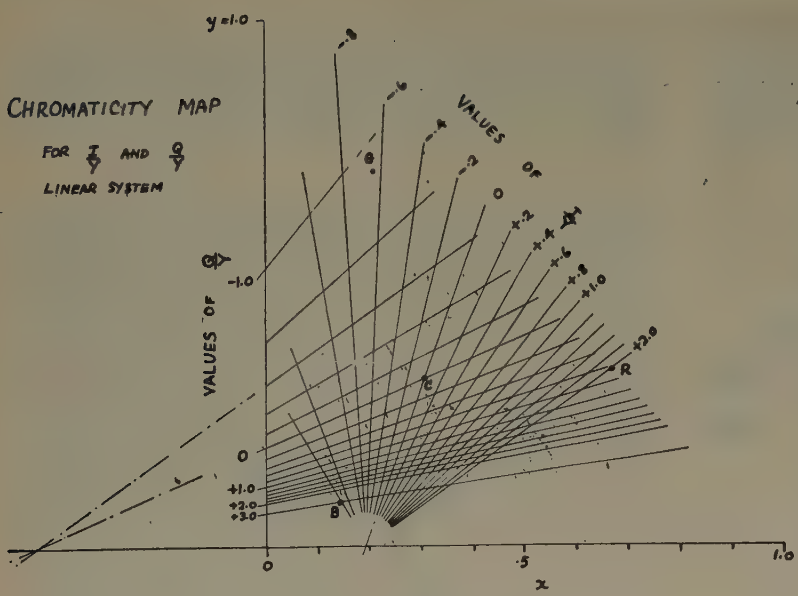


Fig. 9

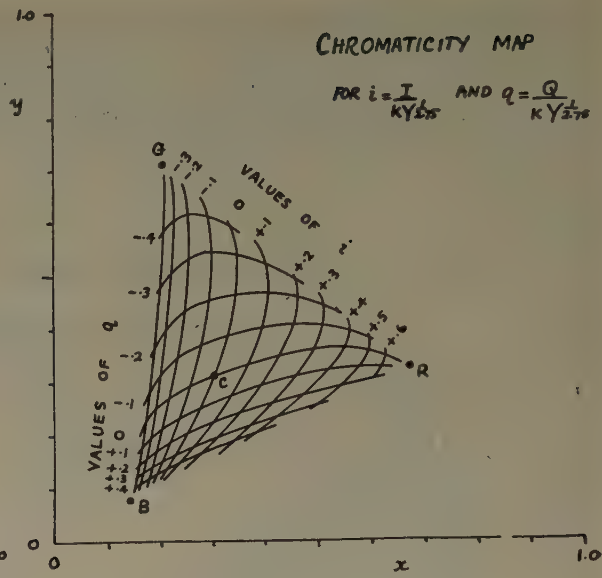


Fig. 10

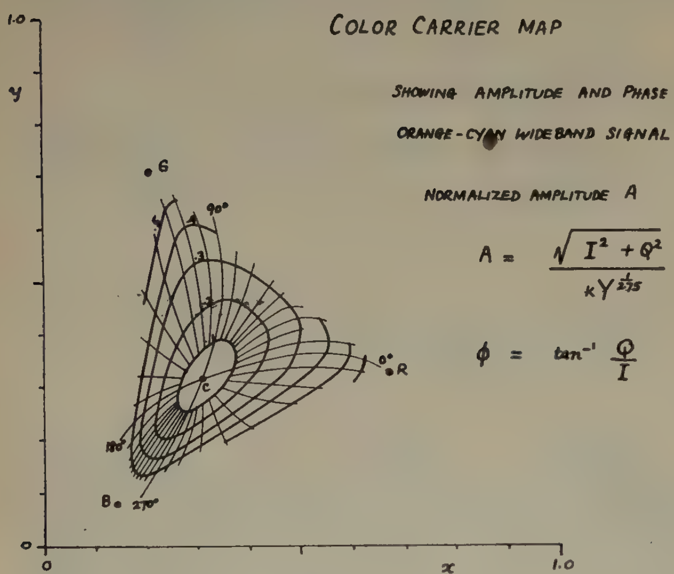


Fig. 11

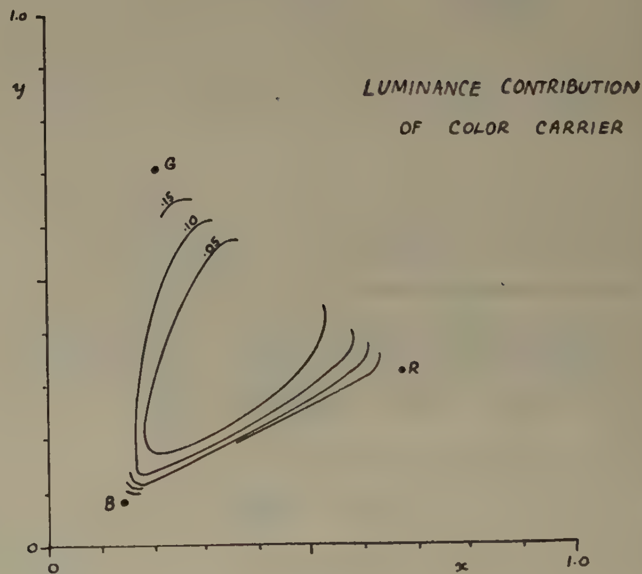


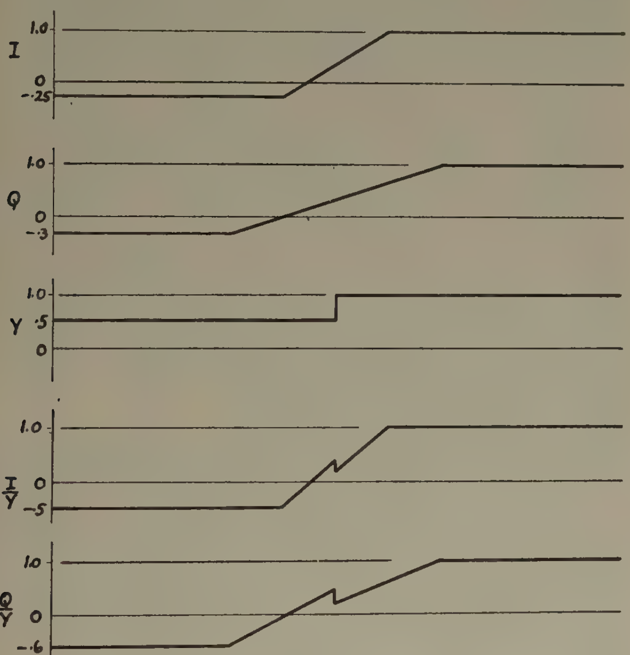
Fig. 12

GB, so that its 2.75 root is unreal. Similar arguments prevent the lines from straying outside of the color triangle on its other two sides. This is not a condition peculiar to the orange-cyan system since it also occurs in the NTSC system. It arises fundamentally, of course, from the use of 2.75 as the gamma index.

A color carrier map for the orange-cyan system is shown in Fig. 11. It will be seen to be generally quite similar in character to the NTSC signal. However, the color carrier specifications have been arranged so as to prevent the phase of the color carrier from affecting the luminance of the display. This modification, which constitutes another subject considered by NTSC, has been referred to as "circular chrominance."

The implication of circular chrominance can perhaps be followed more closely by referring to Fig. 12. This figure shows the relative luminance contribution provided by the color carrier as compared to that provided by the luminance signal itself in the NTSC signal. These curves have been derived from similar curves originally given by Applebaum. They have been rearranged to display the luminance contribution of a color carrier through the argument that all luminance not contributed by the monochrome signal must of necessity come from the color carrier signal in a system of colorimetric fidelity. This diagram is a CIE chromaticity diagram, and shows (a) the location of the points *R*, *G* and *B* of the NTSC primaries, and (b) the loci of colors

for which the luminance provided by the color carrier is 5 per cent, 10 per cent, 15 per cent etc. of the total display luminance; these loci have been indicated by the values .05, .10, and .15 noted upon the corresponding locus. In circular chrominance, the lines of constant color carrier amplitude track the contours of luminance contribution so that, as the color carrier phase is varied, the luminance contribution of the color carrier remains constant since the locus followed by the color conforms to the contours of luminance contribution. The improvement due to circular chrominance can be observed by superimposing the color carrier maps for NTSC chrominance and for circular chrominance upon the luminance contribution contours. The match, while not perfect, will be found to be much better for the case of circular chrominance.



WAVEFORMS AT A COLOR TRANSITION

Fig. 13

As a final illustration of the application of colorimetric principles, let us examine the manner in which a color transition is accomplished in the orange-cyan system. Fig. 13 shows a set of assumed waveforms for I, Q and Y. Due to the different bandwidths involved, the transitions will take different times to accomplish. For simplicity of illustration, the luminance signal has been assumed to jump instantaneously. The I signal has been shown as a sloping transition taking one relative unit of time, while the Q signal, because of its narrower bandwidth, has been shown as occupying two units. The delays have been adjusted so that the transitions are centered.

The quantities I/Y and Q/Y, which determine the chromaticities, have been derived and are shown in the lower pair of waveform diagrams.

These quantities have been transferred to a chromaticity diagram assuming a linear system; the result is shown in Fig. 14. It will be seen that the initial color is

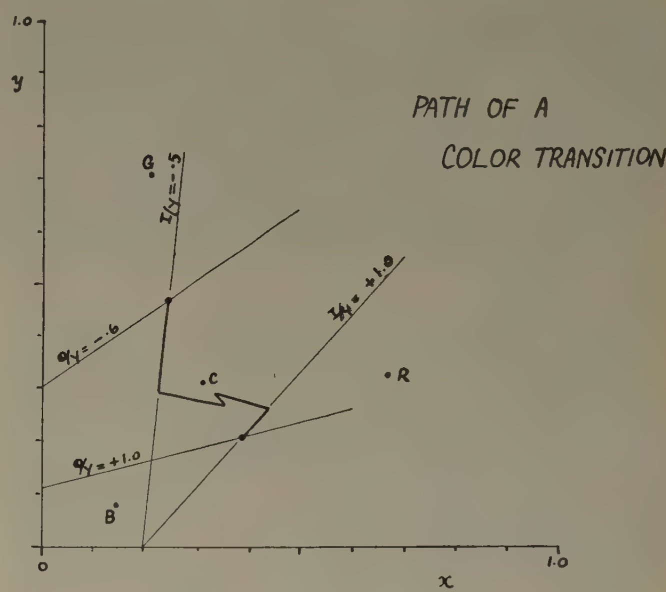


Fig. 14

at the point $Q/Y=-.6$ and $I/Y=-.5$. The first action of the transition is to cause the values of Q/Y to change while I/Y remains constant at $-.5$. This carries the color down the $I/Y=-.5$ ray until the transition begins in the I channel. The color then takes a path determined by the rates of change in the I and Q channels until the instant of the luminance step occurs. At this point, the color abruptly follows a path directed towards the illuminant C point until it is closer to illuminant C in the same ratio that the luminance has increased. The luminance step being completed, the journey towards the $I/Y=+1$ line follows until it is eventually reached at which point I has reached its new value. Q however, has not yet completed its transition; this it continues to do and the color journeys down the $I/Y=1$ ray until it finally arrives at its destination, which is the intersection with the ray $Q/Y=1$. Thus we see that the transition path consists of five separate branches, each one determined by a specific part of the transition cycle.

This illustration has of course, been considerably simplified in the treatment used. However, the method used does seem to indicate the general character of transitions of this kind. The study could obviously be extended to include treatment of the nonlinear case by use of the nonlinear color maps already derived.

The Choice of Axes and Bandwidths for the Chrominance Signals in NTSC Color Television*

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Summary—This paper discusses the way in which bandwidth restriction is applied in the NTSC color television specification to eliminate color "crosstalk" in the received picture. The signal which modulates the subcarrier along one axis is limited by a low-pass filter so that along this axis of the color subcarrier double-sideband conditions may be maintained in transmission and reception. The particular choice of narrow-band axis is not important if the only objective is to eliminate color crosstalk. This leaves one free to make the axes choice hinge upon some important characteristics of the human eye. These eye properties are reviewed as they apply to the NTSC signal specification.

THE NTSC SPECIFICATION for the color picture signal makes use of three voltages derived from the red, green and blue signal outputs of the camera, with operations such as gamma-correction performed on the signals before a combining process is applied. These individual voltages may assume values between zero and unity, depending on the hue and intensity of the light from the area under consideration. In addition, these voltages are of complex form, each containing an average or dc value as well as a bundle of sine waves which are harmonics of the frame frequency.

One part of the color picture signal is formed by adding the three camera signals in a selected proportion. This part of the color picture signal, called the "luminance" signal, carries the information necessary to produce an excellent black-and-white picture on a conventional monochrome receiver. The proportionality values used in this combining process are the relative luminance values of primary colors having the following chromaticities in the CIE system of specification:

	x	y
Red	0.67	0.33
Green	0.21	0.71
Blue	0.14	0.08

when these primaries are mixed to give Illuminant C ($x=0.310$, $y=0.316$). This method of proportioning the luminance signal makes use of the concept of "Constant Luminance"[1] and was designed to make the system less susceptible to external interference such as oscillator radiation and to improve the ability of the color and brightness information to coexist in the limited frequency band.

The coloring or "chrominance" information is carried by a subcarrier which is modulated in amplitude and phase by a combination of the three camera signals in such a way that the instantaneous amplitude of the chrominance subcarrier is proportional to the product of luminance and purity for a picture element, while the phase of the subcarrier is proportional to the dominant wavelength of the picture element.

The NTSC has selected a subcarrier frequency of 3.579545 mc which is related to the line-scanning frequency by a factor of 455/2 to reduce the visibility of the subcarrier on monochrome receivers tuned to the color signal.[2]

Since the color receivers will attenuate signals which lie more than 4.2 mc above the carrier frequency, the sidebands of the subcarrier will remain double sidebands only for modulating frequencies below 0.6 mc. Modulating frequencies above 0.6 mc will be available in single sideband or vestigial sideband components. Unless specific means are utilized, color components with frequencies above 0.6 mc will produce color crosstalk[3] or "quadrature components."

The crosstalk may be completely eliminated by restricting the bandwidth of the signals applied to one of the color encoders at the studio so that this encoder is modulated only by signals with frequencies less than 0.6 mc, thus ensuring that along one axis or phase position of the color subcarrier, double sideband conditions will be maintained in transmission and reception. This restriction, together with an appropriate low-pass filter after a selected decoder in the receiver, will completely eliminate color crosstalk in the received picture.[3–5]

The particular choice of narrow-band axis is not important if the only objective is to eliminate color crosstalk. This leaves one free to make the axes choice hinge upon the characteristics of the human eye. Many new data on vision, accumulated in recent years, are very important for color television. Willmer and Wright[6] have

* Decimal classification: R583. NTSC Technical Monograph No. 14, reprinted by permission of the National Television System Committee from "Color System Analysis," Report of NTSC Panel 12.

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[1] W. F. Bailey, "The constant luminance principle in NTSC color television," Proc. I.R.E., pp. 60–66, this issue.

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[3] *Loc. cit.*, pp. 278–281.

[4] W. F. Bailey and C. J. Hirsch, "Quadrature crosstalk in NTSC color television," Proc. I.R.E., pp. 84–90, this issue.

[5] Paul W. Howells, "A Proposal for a Modification of the Chrominance Signal Specification," NTSC-P13-289.

[6] E. N. Willmer and W. D. Wright, "Colour sensitivity of the fovea centralis," *Nature*, vol. 156, pp. 119–121; July 28, 1945

found that any color, in a small enough patch well centered in the field of vision, can be matched by mixing only two, and not three, "primary" colored lights. The "chromaticity diagram" then becomes merely a straight line. Middleton and Holmes[7] have found that small patches cut from large colored sheets are not as well matched visually by the original sheets as they are by sheets of somewhat differently colored material. Their results show the tendency of the chromaticity diagram to degenerate toward a single line for these small patches and indicate that the two primaries mixed to match the color of a tiny object should be chosen as a barely orange-red and a greenish-blue. Hartridge[8] has made a wide variety of investigations that differ in detail but generally corroborate the above findings. None of the three investigations cited was concerned particularly with television. Observations of sharpness of visibility of color and brightness contrast edges made by Bedford[9] give further corroboration. It is evident from the totality of the work cited that individual observers actually see somewhat differently from one another, but there is full agreement on the general character of the phenomena observed.

As colored objects are decreased in size, four things are found to happen in succession. First, blues become indistinguishable from grays of equivalent brightness and, second, yellows become indistinguishable from grays. In the size range where this happens, browns are confused (in hue but not in brightness) with crimsons, and blues with greens, but reds remain clearly distinct from blue-greens. On the whole, colors with pronounced blue lose blueness, while colors lacking in blue gain blueness; all become less saturated. Third, with still further decrease in size, reds merge with grays of equivalent brightness and, finally, blue-greens also become indistinguishable from gray. For exceedingly small objects, normal visual sensations are devoid of all color connotation, and only perception of brightness remains.

[7] W. E. K. Middleton and M. C. Holmes, "The apparent colors of surfaces of small subtense—a preliminary report," *Jour. Opt. Soc. of Amer.*, vol. 39, 582–592; July, 1949.

[8] H. Hartridge, "The visual perception of fine detail," *Phil. Trans. Roy. Soc.*, London, England, ser. B, vol. 232, pp. 519–671; May 15, 1947.

[9] A. V. Bedford, "Mixed highs in color television," Proc. I.R.E., vol. 38, pp. 1003–1009; September, 1950.

The above information shaped the basic philosophy while a large number of actual observations of pictures produced by varying the narrow-band axis of transmission[5,10–13] led to a choice of axes and bandwidths for chrominance signals which yield following results:

1. Full band transmission of the luminance signal.
2. Moderately wideband, partly single-sideband, transmission of a single color mixture signal distinguishing, for example, orange-red from blue-green.
3. Narrowband, double-sideband, transmission of an additional color-mixture signal distinguishing, for example, green from purple.

The NTSC signal specification describes a signal containing a modulated subcarrier using two different color-mixture channel bandwidths to meet fully color vision needs while avoiding transmission difficulties.

A reference phase is provided for color receivers by applying a "burst" of a sine wave which has the same frequency as the subcarrier. This burst is placed on the horizontal blanking pedestal in a position closely following the horizontal synchronizing pulses. Certain phase choices resulted in minimum visibility of the burst in the return trace, but these phase positions produced the maximum effect on dc restoration so that return-trace blanking would be required in the color receivers. In other phase positions where dc restoration in the receivers would be satisfactory, the visibility of the burst would be such as to require return-trace blanking. It thus seemed evident that blanking of some form would be required in the color receiver regardless of the phase of the burst. Since no other factors seemed compelling in making a choice of the reference phase, it was chosen to be most convenient to use in inexpensive receivers which might not take advantage of additional color detail provided in single-sideband region of transmission.

[10] R. D. Kell and A. C. Schroeder, "Optimum utilization of the radio frequency channel for color television," *RCA Review*, vol. XIV, pp. 133–143; June, 1953.

[11] Demonstration for Subcommittee 9, Subcommittee on the Chrominance Bandwidth of Panel 13 of the NTSC (RCA Laboratories, Princeton, N. J., Aug. 13, 1952) NTSC-P13-287.

[12] Demonstration for Panel 13 of the NTSC (RCA Laboratories, Princeton, N. J., Aug. 26–27, 1952) NTSC-P13-288.

[13] Report of Chrominance Axes Subcommittee 11 of Panel 13 of the NTSC (RCA Laboratories, Princeton, N. J., Jan. 13, 1953) NTSC-P13-332.

The Constant Luminance Principle in NTSC Color Television*

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Summary—**This paper will discuss the constant luminance principle which is used in NTSC color television. The basic ideas involved are developed, and their effect upon the choice of a signal and the design of the receiver is shown. The benefits from the use of the constant luminance principle are indicated.**

What the Constant Luminance Principle Is

IN ORDER TO permit optimum packaging of the color information into a 6 mc channel, the NTSC signal specifications make use of the constant luminance principle, which is "Signals in the band-shared color-carrier channel shall not affect the luminance of the reproduced picture."

Practicing of the constant luminance principle is fundamentally a receiver design problem; however, since in a receiver using this principle the reproduced luminance is controlled by the monochrome signal, the transmitted monochrome signal should be representative of luminance to obtain correct color reproduction. This fact is recognized in the NTSC specifications.

Reason for Use of the Constant Luminance Principle

The use of the constant luminance principle in a color receiver is desirable because it minimizes the subjective effect of the additional noise received in the color-difference channel of the receiver. Spurious signals such as noise or interference in the color-difference channel of a constant luminance receiver should produce only chromaticity variations in the picture, and this type of variation has considerably less subjective annoyance value to the viewer than does luminance noise.

Since the signals in the bandshared color-difference channel of the receiver are heterodyned to a low frequency, the noise or interference present in that band becomes more noticeable as it has a relatively coarse pattern in the reproduced picture and this is a strong reason for minimizing the fluctuations in luminance from the color-difference channel.

Characteristic of Human Vision

An experiment which shows the fact that the eye has more sensitivity to spatial and temporal variations in luminance than to variations in chromaticity will be described.

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Fig. 1A shows schematically an arrangement which was used to obtain data on this characteristic. In performing the experiment, the two rasters were well registered, the picture tubes were biased to moderate beam currents, and a certain amount of random noise was produced on the red raster. By means of a phase in-

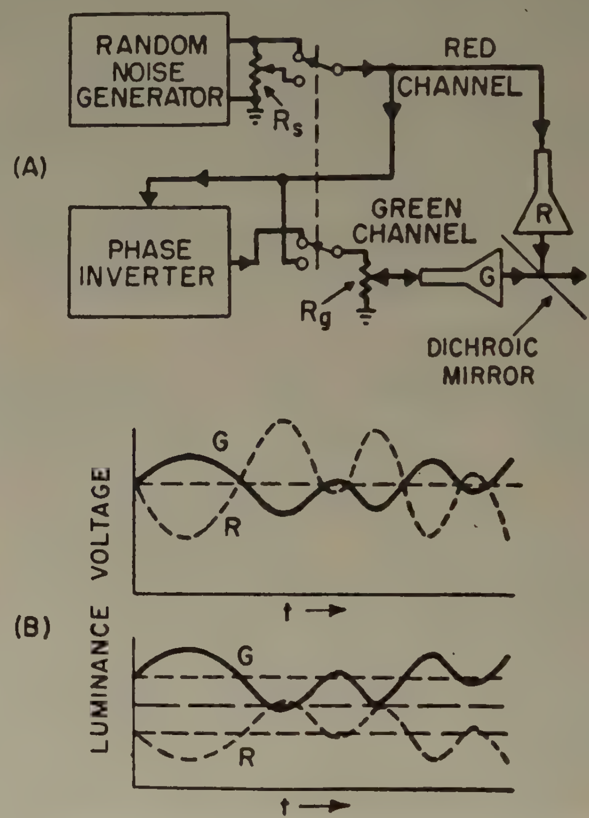

Fig. 1—Test set-up (A) and wave forms (B) for measuring annoyance of luminance noise versus color noise.

verter and an attenuator R_G the amount of oppositely phased noise on the green raster could be adjusted, and it was found that there was a minimum in the total noise perceived in the composite image of the two rasters, at a particular setting of R_G. To evaluate the subjective improvement, the switch was then thrown to the lower position, which applied a like noise signal to the two picture tubes. Attenuator R_S was then adjusted to produce the same subjective noise as obtained at the optimum setting of R_G. These experiments indicated that with the like noise signal attenuated 6 or 8 db, as compared to the oppositely phased noise, the subjective effect for the two conditions was about the same. Fig. 1B indicates the conditions which obtain when the attenuator R_G is adjusted for minimum per-

ceptible noise—the signal voltage to the green picture tube is about half of that for the red picture tube. This results in the production of luminance variations for the two tubes which are substantially equal but of opposite polarity so that the sum of the two luminances remains constant.

It is possible that due to nonlinearity of the apparatus the two luminances did not add up to a constant instantaneous value and that the 6 to 8 db improvement would have been higher had it not been for this departure from true constant luminance for the sum of the individual luminances, such as will be treated in a later section. Of course, the relative contributions to the total luminance are varying with the noise voltage and this results in a random variation in chromaticity. This demonstrates that the eye is considerably more sensitive to luminance fluctuations than to chromaticity fluctuations both in time and in space. The constant luminance principle which is used in designing receivers for color television is based upon this experiment.

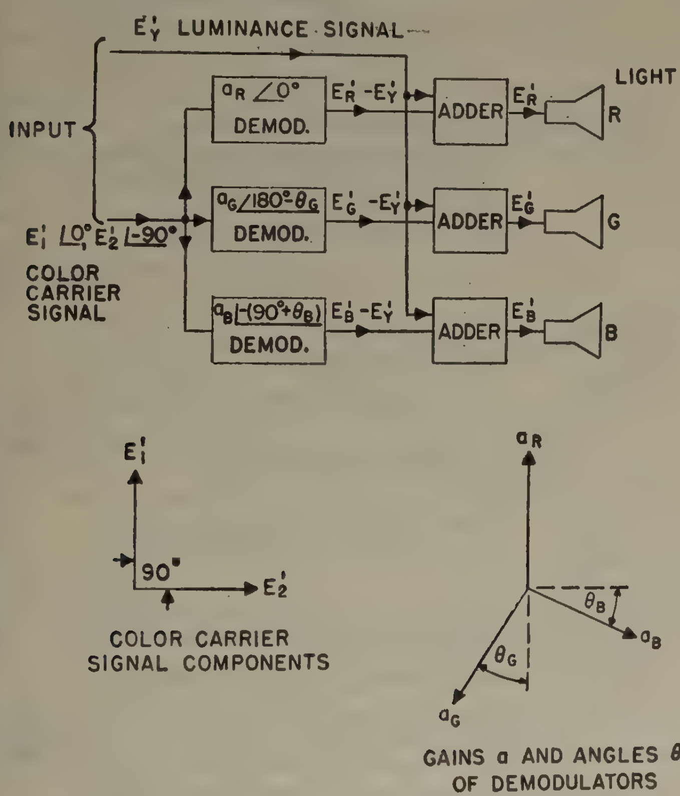

Fig. 2—Schematic receiver.

Effect of Constant Luminance Principle in Receiver Design (Linear Receiver)

The constant luminance principle in general terms is the method of proportioning the receiver so that the chrominance channel does not affect luminance. This proportioning can be done with any color-carrier composition. In Fig. 2 there is shown the basic decoding portions of a color receiver. The color-carrier signal is stated in terms of the two quadrature components $E_1'\angle 0°$ and $E_2'\angle -90°$.

The use of the primes on voltages denotes voltages after gamma correction.

The color-carrier signal is demodulated by synchronous detectors whose output is proportional to the component of the color carrier taken in a particular direction relative to the color carrier times the gain of the particular synchronous detector. The demodulating gains and axes are, for red $a_R\angle 0°$, for green $a_G\angle 180°-\theta_G°$, and for blue $a_B\angle -(90°+\theta_B°)$. This demodulation may also be accomplished by the use of only two demodulators and a matrix to obtain the three output signals.

The output signals from the three demodulators are color-difference signals, and they are:

For the red channel $E_R'-E_Y'=E_1'a_R$, since the red demodulation axis is along the component E_1' and in quadrature to E_2'.

For the green channel $E_G'-E_Y'=-E_1'a_G \cos\theta_G -E_2'a_G \sin\theta_G$, since both the color carrier components E_1' and E_2' have components along the green demodulation axis.

For the blue channel, similarly, $E_B'-E_Y'=E_2'a_B \cos\theta_B-E_1'a_B \sin\theta_B$.

The signal applied to a particular electron gun is comprised of the sum of the luminance signal and a particular color-difference signal. Thus for the red gun

$$E_R' = E_Y' + (E_R' - E_Y') = E_Y' + E_1'a_R$$

For the green gun,

$$\begin{aligned} E_G' &= E_Y' + (E_G' - E_Y') \\ &= E_Y' - E_1' a_G \cos\theta_G - E_2'a_G \sin\theta_G \end{aligned}$$

And for the blue gun,

$$\begin{aligned} E_B' &= E_Y' + (E_B' - E_Y') \\ &= E_Y' - E_1'a_B \sin\theta_B + E_2'a_B \cos\theta_B. \end{aligned}$$

Each of these signals will control the luminance from its respective phosphor by the relations:

$$Y_R = L_RE_R'$$
$$Y_G = L_GE_G'$$
$$Y_B = L_BE_B'$$

where the L's are defined as luminance produced by one reproducing primary light source per volt of signal at the place marked "Input" in Fig. 2.

Thus luminance from each phosphor is expressed:

$$Y_R = L_RE_R' = L_R[E_Y' + E_1'a_R]$$
$$Y_G = L_GE_G' = L_G[E_Y' - E_1'a_G \cos\theta_G - E_2'a_G \sin\theta_G]$$
$$Y_B = L_BE_B' = L_B[E_Y' - E_1'a_B \sin\theta_B + E_2'a_B \cos\theta_B].$$

The total reproduced luminance

$$Y_T = Y_R + Y_G + Y_B$$
$$\begin{aligned} Y_T = {} & E_Y'[L_R + L_G + L_B] \\ & + E_1'[L_Ra_R - L_Ga_G \cos\theta_G - L_Ba_B \sin\theta_B] \\ & + E_2'[- L_Ga_G \sin\theta_G + L_Ba_B \cos\theta_B]. \end{aligned}$$

The first term on the right side is the reproduced luminance from the luminance signal E_Y'. The second two terms are the reproduced luminance from the color carrier, and for the constant luminance condition they are zero. Thus:

$$L_R a_R - L_G a_G \cos\theta_G - L_B a_B \sin\theta_B = 0$$
$$- L_G a_G \sin\theta_G + L_B a_B \cos\theta_B = 0.$$

These two equations state that the luminance produced by components along the E_1' axis is zero and that it is also zero from components along the E_2' axis. This may be generalized as:

$$L_R a_R \underline{/0°} + L_G a_G \underline{/180° - \theta_G} + L_B a_B \underline{/-(90° + \theta_B)} = 0.$$

This equation, for a linear system, is the basic idea involved in the constant luminance principle. It does not involve the composition of the color carrier, but does involve the proportioning of the parts of the chrominance channel in the receiver. Thus, the constant luminance condition may be obtained with *any* color carrier by suitable design of the receiver. If the receiver is to make pictures with the proper color when operating according to the constant luminance principle, then the monochrome signal should be proportional to luminance since it has the only control over the reproduced luminance. If the monochrome signal is not proportional to luminance, then the reproduced luminance and chromaticity will both be in error.

Effect of Interfering Signal on Constant Luminance Receiver (Linear Receiver)

To see the action of the constant luminance principle in a linear receiver when an interfering signal is present, consider Fig. 3. The receiver is assumed to be designed for a signal having the composition of the NTSC specification.

Assume that the transmitted signal is that for a uniformly illuminated raster of reference chromaticity (Standard Source C), that is, there is a luminance signal E_Y', but no transmitted color difference signals. Let there also be received an interfering signal $E_A \cos\omega_A t$ as shown in Fig. 3A. The video signal from the second detector will be $E_Y' + E_A' \cos\omega_A t$.

We shall limit the discussion here to the effect of the interfering component $E_A \cos\omega_A t$ in the color-difference channel of the receiver.

The interfering signal $E_A \cos\omega_A t$ has components along the E_1' and E_2' color carrier-signal components which vary sinusoidally in time at the difference frequency between the color carrier and the interfering frequencies. The component along E_1' is $E_A \cos(\omega_A - \omega)t$ and that along E_2' is $-E_A \sin(\omega_A - \omega)t$.

The signals in the three color-difference channels from the interfering signals, are, using the previous equations:

In the $E_R' - E_Y'$ channel,

$$a_R E_A \cos(\omega_A - \omega)t.$$

In the $E_G' - E_Y'$ channel,

$$- a_G E_A \cos(\omega_A - \omega)t \cos\theta_G + a_G E_A \sin(\omega_A - \omega)t \sin\theta_G$$

And in the $E_B' - E_Y'$ channel,

$$- a_B E_A \cos(\omega_A - \omega)t \sin\theta_B - a_B E_A \sin(\omega_A - \omega)t \cos\theta_B.$$

According to NTSC specification, the color carrier composition for this case is

$$E_1' = \frac{E_R' - E_Y'}{1.14} \quad \text{and} \quad E_2' = \frac{E_B' - E_Y}{2.03}.$$

This means that the red color-difference signal is obtained by demodulating in quadrature to the E_2' axis with a gain $a_R = 1.14$. The quadrature relation is used so that E_2' produces no component in the red color-difference output signal.

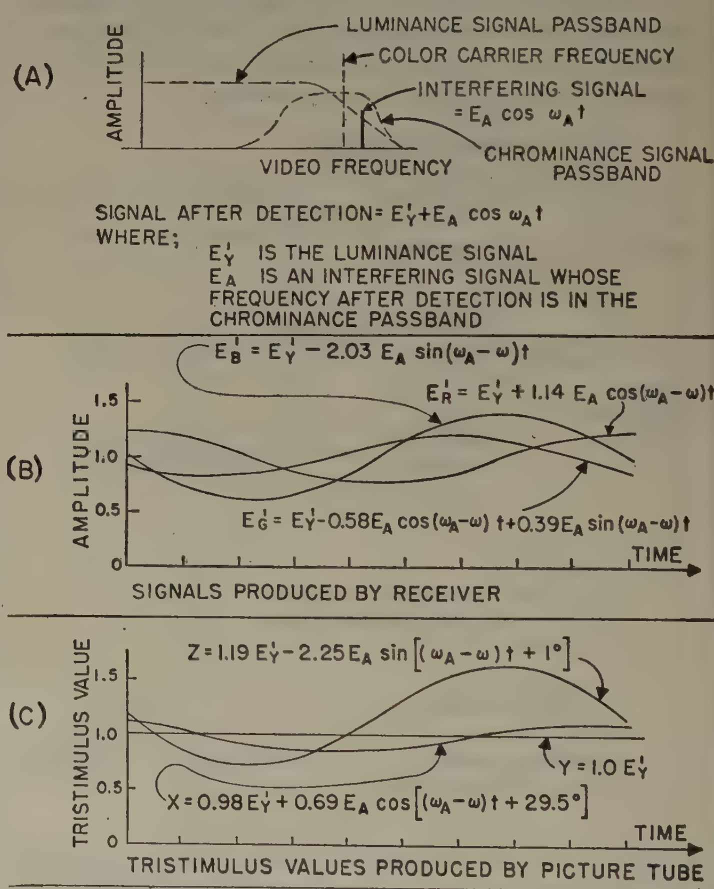

Fig. 3—Constant luminance receiver with interference.

The blue color difference signal is obtained by demodulating in quadrature to the E_1' axis with a gain $a_B = 2.03$. Thus angle θ_B is equal to zero in this case.

For the NTSC color-carrier composition, we can find the gain a_G and angle θ_G by solving the conditions for constant luminance previously given. These conditions were that the luminance produded by the E_1' component and by the E_2' component be equal to zero. The equations to be satisfied to obtain this condition are

$$L_R a_R - L_G a_G \cos\theta_G - L_B a_B \sin\theta_B = 0$$
$$- L_G a_G \sin\theta_G + \sum\nolimits_B a_B \cos\theta_B = 0.$$

For this case in which the color carrier component $E_R'-E_Y'$ is in quadrature with the component $E_B'-E_Y'$, the angle $\theta_B=0°$ and this simplifies the equations to

$$L_R a_R - L_G a_G \cos\theta_G = 0$$
$$-L_G a_G \sin\theta_G + L_B a_B = 0.$$

The primaries assumed for this example are those specified by NTSC for which $L_R=0.30$, $L_G=0.59$, and $L_B=0.11$ when evaluated according to the previous definition given for these quantities. Thus since a_R and a_B are known, these equations may be solved for a_G and θ_G and the values found to be:

$$a_G = 0.703$$
$$\theta_G\ 34° \text{ for which } \begin{cases}\cos\theta_Y = 0.829\\ \sin\theta_Y = 0.559.\end{cases}$$

Using the relations given above, and substituting in the numerical values,

$$E_R' - E_Y' = 1.14E_1'$$
$$E_G' - E_Y' = -0.583E_1' - 0.393E_2'$$
$$E_B' - E_Y' = 2.03E_2'.$$

and when the components of the interfering signal along E_1' and E_2' are substituted in, the color-difference signals become:

$$E_R' - E_Y' = 1.14E_A\cos(\omega_A-\omega)t$$
$$E_G' - E_Y' = -0.583E_A\cos(\omega_A-\omega)t + 0.393E_A\sin(\omega_A-\omega)t$$
$$E_B' - E_Y' = -2.03E_A\sin(\omega_A-\omega)t$$

The signals which control the phosphors are

$$E_R' = E_Y' + (E_R' - E_Y')$$
$$E_G' = E_Y' + (E_G' - E_Y')$$
$$E_B' = E_Y' + (E_B' - E_Y')$$

and thus are:

$$E_R' = E_Y' + 1.14E_A\cos(\omega_A-\omega)t$$
$$E_G' = E_Y' - 0.583E_A\cos(\omega_A-\omega)t + 0.393E_A\sin(\omega_A-\omega)t$$
$$E_B' = E_Y' - 2.03E_A\sin(\omega_A-\omega)t.$$

These three signals have been plotted for a short time interval during a line in Fig. 3B. For the plot EY' was assumed to equal 1.0 and E_A was taken equal to 0.2 EY'.

If the picture tube produces light of reference chromaticity (Standard Source C, $x=0.310$, $y=0.316$) for the case of zero color-carrier signal, then it can be shown for the normalized signals used in the discussion that the light output from the three primary colors evaluated as tristimulus values is:

From the red phosphor (0.61 unit of X, 0.30 unit of Y and 0.00 unit of Z) per volt of driving signal.

From the green phosphor (0.17 unit of X, 0.59 unit of Y, and 0.07 unit of Z) per volt of driving signal.

From the blue phosphor (0.20 unit of X, 0.11 unit of Y, and 1.12 unit of Z) per volt of driving signal.

Thus, the total tristimulus value produced is:

From the red phosphor

$$=(0.61X+0.30Y+0.00Z)(E_Y'+1.14E_A\cos(\omega_A-\omega)t).$$

From the green phosphor

$$=(0.17X+0.59Y+0.07Z)(E_Y'-0.583E_A\cos(\omega_A-\omega)t + 0.393E_A\sin(\omega_A-\omega)t).$$

From the blue phosphor

$$=(0.20X+0.11Y+1.12Z)(E_Y'-2.03E_A\sin(\omega_A-\omega)t).$$

Summing these tristimulus values:

$$=E_Y'[0.98X+1.00Y+1.19Z] + E_A[0.60X\cos(\omega_A-\omega)t-0.34X\sin(\omega_A-\omega)t - 0.04Z\cos(\omega_A-\omega)t-2.25Z\sin(\omega_A-\omega)t]$$

which may also be expressed as

$$=Y(1.00E_Y')+X(0.98E_Y'+0.69E_A\cos[(\omega_A-\omega)t+29.5°]) + Z(1.19ZE_Y'-2.25E_A\sin[(\omega_A-\omega)t+1.0°]).$$

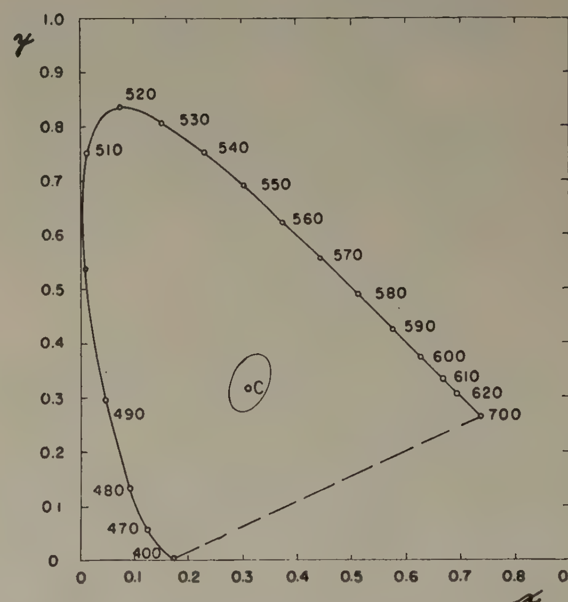

Fig. 4—CIE chromaticity diagram showing chromaticity variations from interfering signal.

These values are shown in Fig. 3C for $E_A=0.2EY'$. The value of Y which is proportional to the luminance is seen to be independent of the interfering signal E_A, and only governed by the luminance signal E_A'. The chromaticity of the raster is affected by the interference since the tristimulus values X and Z are varied by E_A. The locus of the chromaticity values through which the light will vary with this interfering signal has been plotted as the closed loop encircling the point C on the chromaticity diagram of Fig. 4.

The Constant Luminance System with a Nonlinear Receiver

To consider the constant luminance principle when the receiver is nonlinear, an approximation to the actual case will be discussed. The schematic receiver and the signal of Fig. 2 will be used. The signals applied to the picture tube, as previously shown, are:

$$E_R' = E_Y' + E_1'a_R$$
$$E_G' = E_Y' - E_1'\, a_G \cos\theta_G - E_2'a_G \sin\theta_G$$
$$E_B' = E_Y' - E_1' \sin\theta_B + E_2'a_B \cos\theta_B.$$

The picture tube will be assumed nonlinear, having a power law of γ, equal for the three colors, so that the luminance produces is related to the driving signals as follows:

$$Y_R = L_R E_R'^r$$
$$Y_G = L_G E_G'^r$$
$$Y_B = L_B E_B'^r.$$

The luminance produced by each phosphor will then be:

$$Y_R = L_R E_Y'^r\left(1 + \frac{E_1'}{E_Y'}a_R\right)^r$$
$$Y_G = L_G E_G'^r\left[1 - \frac{E_1'}{E_Y'}a_G\cos\theta_G - \frac{E_2'}{E_Y'}a_G\sin\theta_G\right]^r$$
$$Y_G = L_B E_Y'^r\left[1 - \frac{E_1'}{E_Y'}a_B\sin\theta_B + \frac{E_2'}{E_Y'}a_B\cos\theta_B\right]^r.$$

These expressions may be expanded by use of the expression:

$$(1+x)^\gamma = 1 + \gamma x + \frac{\gamma(\gamma-1)}{2!}x^2 + \frac{\gamma(\gamma-1)(\gamma-2)}{3!}x^3 + \cdots.$$

When this is done, the results are:

$$Y_R = E_Y'^\gamma L_R\left[1 + \gamma\frac{E_1'}{E_Y'}a_R + \frac{\gamma(\gamma-1)}{2!}\left(\frac{E_1'}{E_Y'}\right)^2 a_R^2 + \cdots\right]$$
$$Y_G = E_Y'^\gamma L_G\left[1 + \gamma\left(-\frac{E_1'}{E_Y'}a_G\cos\theta_G - \frac{E_2'}{E_Y'}a_G\sin\theta_G\right]\right.$$
$$\left. + \frac{\gamma(\gamma-1)}{2!}\left(-\left(\frac{E_1'}{E_Y'}\right)a_G\cos\theta_G - \frac{E_2'}{E_Y'}a_G\sin\theta_G\right)^\gamma + \cdots\right]$$
$$Y_B = E_Y'^\gamma L_B\left[1 + \gamma\left(-\frac{E_1'}{E_Y'}a_B\sin\theta_B + \frac{E_2'}{E_Y'}a_B\cos\theta_B\right)\right.$$
$$\left. + \frac{\gamma(\gamma-1)}{2!}\left(-\frac{E_1'}{E_Y'}a_B\sin\theta_B + \frac{E_2'}{E_Y'}a_B\cos\theta_B\right)^2 + \cdots\right].$$

All terms above the second power will be ignored. This is accurate for $\gamma = 2$, since all terms of power three or greater contain the coefficient $(\gamma - 2)$ which is equal to zero when $\gamma = 2$.

The total reproduced luminance is:

$$Y_T = Y_R + Y_G + Y_B.$$

The total reproduced luminance will be expressed in the normalized form $Y_T/E_Y'^\gamma$ which is the ratio of the actual reproduced luminance Y_T to the value produced by the luminance signal $E_Y'^\gamma$. This ratio is:

$$\frac{Y_T}{E_Y'^\gamma} = L_R\left[1 + \gamma\left(\frac{E_1'}{E_Y'}\right)a_R + \frac{\gamma(\gamma-1)}{2!}\left(\frac{E_1'}{E_Y'}\right)^2 a_R^2\right]$$
$$+ L_G\left[1 + \gamma\left(-\left(\frac{E_1'}{E_Y'}\right)a_G\cos\theta_G - \left(\frac{E_2'}{E_Y'}\right)a_G\sin\theta_G\right]\right.$$
$$\left. + \frac{\gamma(\gamma-1)}{2!}\left(-\left(\frac{E_1'}{E_Y'}\right)a_G\cos\theta_G - \left(\frac{E_2'}{E_Y'}\right)a_G\sin\theta_G\right)^2\right]$$
$$+ L_B\left[1 + \gamma\left(-\left(\frac{E_1'}{E_Y'}\right)a_B\sin\theta_B + \left(\frac{E_2'}{E_Y'}\right)a_B\cos\theta_B\right)\right.$$
$$\left. + \frac{\gamma(\gamma-1)}{2!}\left(-\left(\frac{E_1'}{E_Y'}\right)a_B\sin\theta_B + \left(\frac{E_2'}{E_Y'}\right)a_B\cos\theta_B\right)^2\right].$$

The terms will be collected and expressed as coefficients of E_1'/E_Y' and E_2'/E_Y' to various powers. The result is:

$$\frac{Y_T}{E_Y'^\gamma} = (L_R + L_G + L_B) + \gamma\left[\frac{E_1'}{E_Y'}(a_R L_R - a_G L_G\cos\theta_G - a_B L_B\sin\theta_B) + \frac{E_2'}{E_Y'}(-a_G L_G\sin\theta_G + a_B L_B\cos\theta_B)\right]$$
$$+ \frac{\gamma(\gamma-1)}{2}\left[L_R\left(\frac{E_1'}{E_Y'}\right)^2 a_R^2\right.$$
$$+ L_G\left\{\left(\frac{E_1'}{E_Y'}\right)^2 a_G^2\cos^2\theta_G + \frac{2E_1'E_2'}{E_Y'^2}a_G^2\cos\theta_G\sin\theta_G + \left(\frac{E_2'}{E_Y'}\right)^2 a_G^2\sin^2\theta_G\right\}$$
$$\left. + L_B\left\{\left(\frac{E_1'}{E_Y'}\right)^2 a_B^2\sin^2\theta_B - \frac{2E_1'E_2'}{E_Y'^2}a_B^2\sin\theta_B\cos\theta_B + \left(\frac{E_2'}{E_Y'}\right)^2 a_B^2\cos^2\theta_B\right\}\right].$$

The first term on the right side represents the contribution to luminance of the luminance signal.

The second term is the first order contribution from the color carrier. In a receiver designed in accordance

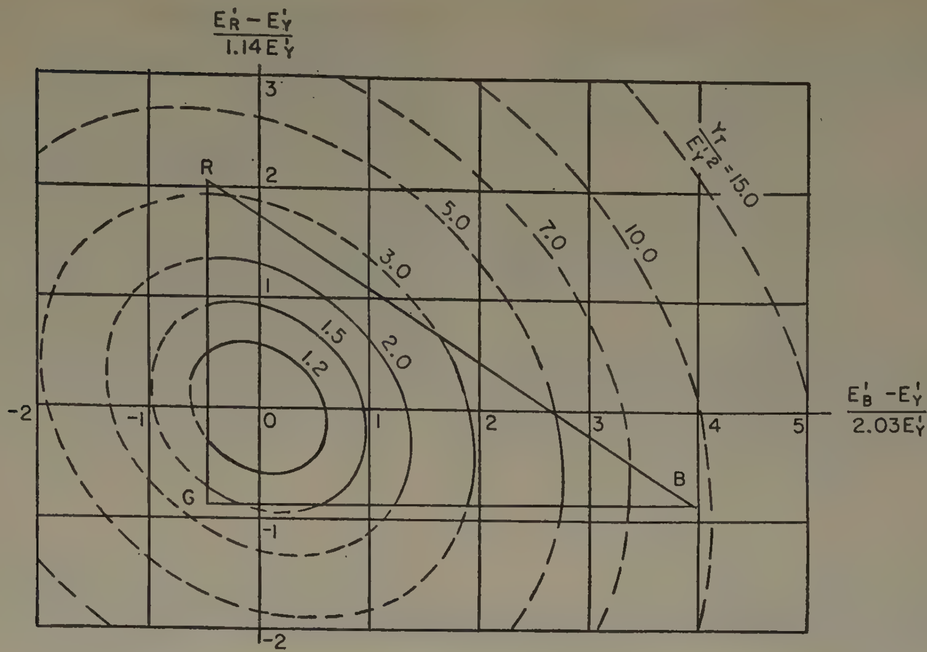

Fig. 5—Reproduced luminance as a function of color carrier for a square law receiver.

with the first order approximation of the constant luminance principle, this term is zero, and so contributes nothing to the luminance, as was shown in the preceding section. This occurs if

$$a_R L_R - a_G L_G \cos\theta_G - a_B L_B \sin\theta_B = 0$$
$$- a_G L_G \sin\theta_G + a_B L_B \cos\theta_B = 0.$$

The third term, which contains E_1'/E_Y' and E_2'/E_Y' to the second power, and the term $E_1'E_2'/E_Y'2$, contributes some deviation from constant luminance as a function of the amplitude of the color-carrier components.

The effect of these terms is shown in Fig. 5, for the NTSC signal, which is a plot of ratio of the reproduced luminance T_T, to the value produced by the luminance signal along $E_Y'^2$ in terms of the color carrier. The NTSC values used for this figure are as follows:

$$E_1' = \frac{E_R' - E_Y'}{1.14} \qquad \theta_B = 0°$$
$$\theta_G = 34°$$
$$E_2' = \frac{E_B' - E_Y}{2.03} \qquad a_R = 1.14$$
$$a_G = 0.703$$
$$a_B = 2.03.$$

The plot is on normalized color-carrier co-ordinates

$$\frac{E_R' - E_Y'}{1.14E_Y'} \quad \text{and} \quad \frac{E_B' - E_Y'}{2.03E_Y'}.$$

The elliptical contours are the loci of color-carrier amplitude and phase for which the actual reproduced luminance is greater by the factors on each ellipse than the luminance which would have been produced by the luminance signal alone for a square law receiver.

The points labelled R, G, and B in Fig. 5 show the value of the normalized color carrier to produce the chromaticity of the primaries referenced by the NTSC. The color gamut of the receiver lies within the triangle connecting the points R, G, and B.

It should be noted that for a receiver of square law characteristic, the ellipses are seen to deviate only slightly from circles. This means that the reproduced luminance does not depend as strongly upon the color-carrier phase as it does upon the amplitude.

The Circular Subcarrier

It is possible to so proportion the coefficients of the terms in $(E_1'/E_Y')^2$ and $(E_2'/E_Y')^2$ in the expression for $Y_T/E_Y'^2$ so that (1) the coefficients of $(E_1'/E_Y')^2$ and $(E_2'/E_Y')^2$ are equal, and (2) the coefficient of the product $E_1'E_2'/E_Y'^2$ equals zero. When this is done, the elliptical loci of Fig. 5 are converted to circular loci, so that the reproduced luminance is then independent of the color-carrier phase. This is the "circular" color carrier which was discussed in Panel 13. With the circular carrier, since the luminance error in the reproduction depends only upon the normalized color-carrier amplitude, it is possible to modify the reproduced luminance in the receiver to the correct value by using a correction signal which varies with the normalized color-carrier amplitude. It was felt, however, that the color carrier according to the NTSC field test specifications was close enough to being free from luminance error as a function of the color-carrier phase as not to warrant the deviation from the quadrature relation between $E_R' - E_Y'$ and $E_B' - E_Y'$.

Mathematically, the conditions for circularity of the color carrier, are, in addition to satisfying the conditions

for constant luminance operation already given, that

$$L_B a_B^2 + L_G a_G^2 \cos^2\theta_G + L_B a_B^2 \sin^2\theta_B = L_G a_G^2 \sin^2\theta_G + L_B a_B^2 \cos^2\theta_B$$

and

$$L_G a_G^2 \cos\theta_G \sin\theta_G - L_B a_B^2 \sin\theta_B \cos\theta_B = 0.$$

The color carrier can be proportioned to satisfy these equations.

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Mathematical Formulations of the NTSC Color Television Signal*

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Summary—**The NTSC color television signal specification may be presented mathematically in a variety of ways, each yielding identical total signals but using a number of different components. In this paper, the presentations are in terms of (1) two color-difference signals, (2) camera primary signals, (3) three color-difference signals, and (4) symmetrical components. The formulation of the signal specification when high-frequency components are present in the signal is also considered.**

The Color Picture Signal Expressed in Terms of the Red and Blue Color-Difference Signals

THE NTSC COLOR Field Test Specifications released for publication February 2, 1953, specify the color picture signal in terms of the following equations:

$$E_M = E_Y + E_Q \sin(\omega t + 33°) + E_I \cos(\omega t + 33°) \quad (1)$$

where

$$E_Q = 0.41(E_B - E_Y) + 0.48(E_R - E_Y) \quad (2)$$

$$E_I = -0.27(E_B - E_Y) + 0.74(E_R - E_Y) \quad (3)$$

$$E_Y = 0.59E_G + 0.30E_R + 0.11E_B \quad (4)$$

and $\omega = 2\pi$ times the frequency of the color subcarrier. The voltages E_G, E_R and E_B are signals derived from the green, red and blue signal outputs of the camera, with operations such as gamma-correction performed on the signals before the combination shown in the above equations are accomplished. These individual voltages may assume values between zero and unity, depending on the hue and intensity of the light from the area under consideration.

The bandwidth assigned prior to modulation to the color-difference signals E_Q and E_I are:

Q-channel bandwidth

at 400 kc less than 2 db down
at 500 kc less than 6 db down
at 600 kc at least 6 db down

I-channel bandwidth

at 1.3 mc less than 2 db down
at 3.6 mc at least 20 db down

For color-difference signal components with frequencies less than 500 kilocycles, (1) may be written

$$E_M = E_Y + \frac{1}{1.14}\left\{\frac{1}{1.78}(E_B - E_Y)\sin\omega t + (E_R - E_Y)\cos\omega t\right\} \quad (5)$$

or simply

$$E_M = E_Y + 0.493(E_B - E_Y)\sin\omega t + 0.877(E_R - E_Y)\cos\omega t. \quad (6)$$

Equations (4) and (6) show that the signal contains a main video signal E_Y which conveys only luminance information and which is capable of producing an excellent black-and-white picture on a conventional monochrome receiver. The chrominance information is carried on a color-subcarrier and consists of two independent components transmitted as a red color-difference signal and a blue color-difference signal.

The phases of the signals in (1), (5) and (6) are referred to the color-carrier reference signal which is described by the equation $E_S = A(t)\sin(\omega t + 180°)$ and (2) therefore states that the $(E_R - E_Y)$ phasor lags the color-carrier reference signal by 90 degrees.

* Decimal classification: R583. NTSC Technical Monograph No. 4A, reprinted by permission of the National Television System Committee from "Color System Analysis," Report of NTSC Panel 12.
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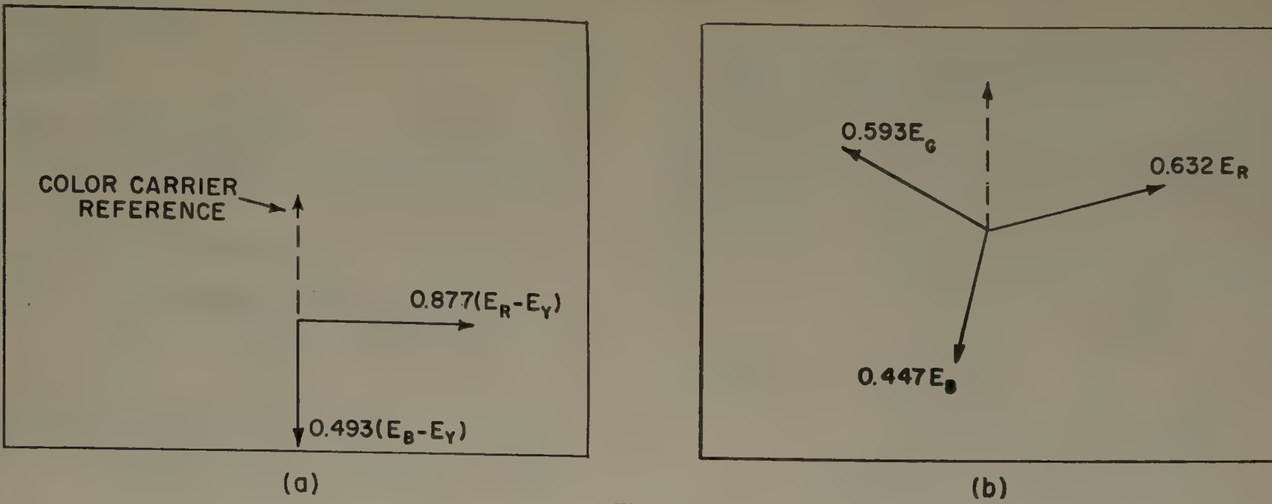


Fig. 1

It may be noted from the previous equations that when the three camera signal voltages become equal (Illuminant C, $x=0.310$, $y=0.316$), the carrier-color signal becomes zero in amplitude.

The following discussion of the several ways of expressing the signal, and the several vector diagrams pertains only to dc values or to components with frequencies below 500 kilocycles, so that (6) is valid.

Fig. 1(a) shows the subcarrier components of (6) displayed in the usual vectorial presentation associated with alternating-current analysis. Usually, the rms values of sine waves are used on the vector diagrams.[1] In this paper, the peak values are shown to make an easy comparison with the equations.

The two vector components in Fig. 1(a) are shown for the maximum values that each may achieve. The actual values obtaining for these components are displayed in Fig. 2 opposite. For instance when a red picture of such a nature that $E_B=E_G=0$ while $E_R=1$ is produced, $E_Y=0.3$ while $E_B-E_Y=-0.3$ and $E_R-E_Y=0.7$ so (6) becomes

$$E_M = 0.3 - 0.1479 \sin \omega t + 0.6139 \cos \omega t = 0.3 + 0.632 \sin (\omega t - 256.5°). \quad (7)$$

The two color-difference signals are shown in Fig. 2(a), where the total carrier-color signal is marked SUM. Other conditions of the color-difference components are shown in Figs. 2(b) to 2(f) on page 68, together with the total carrier-color signal formed from the sum of the two components.

The total vector sum of the color-difference signals is shown (Fig. 3) for following camera signal conditions:

The Color Picture Signal Specification in Terms of the Primary Signals

The color picture signal may be expressed in terms of the primary camera signals E_G, E_R and E_B by substituting (4) in (6), and collecting terms. Then

$$E_M = E_Y + 0.447E_B \sin (\omega t - 12.5°) + 0.593E_G \sin (\omega t - 119.5°) + 0.632E_R \sin (\omega t - 256.5°) \quad (8)$$

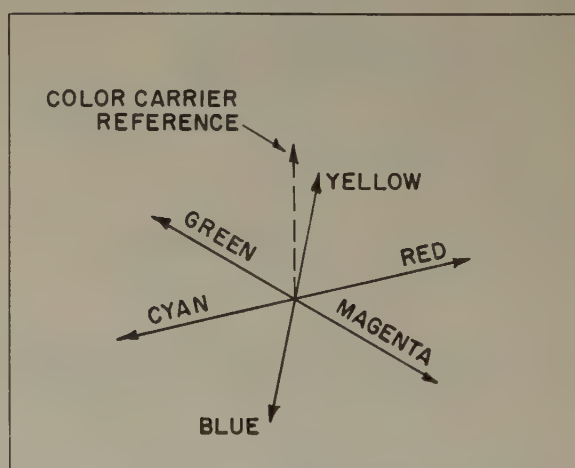


Fig. 3

The vector representation of the chrominance portion of (8) is shown in Fig. 1(b). The maximum value of each component is shown here. It is evident from this diagram that when the maximum values occur simultaneously ($E_G=E_R=E_B=1$), the vector sum is zero and the carrier-color signal disappears (Illuminant C). The actual values obtaining for the com-

Color Transmitted	E_G	E_R	E_B	E_Y	E_G-E_Y	E_R-E_Y	E_B-E_Y	E_Q	E_I
Green	1	0	0	0.59	0.41	−0.59	−0.59	−0.525	−0.28
Yellow	1	1	0	0.89	0.11	0.11	−0.89	−0.31	0.32
Red	0	1	0	0.3	−0.3	0.7	−0.3	0.21	0.60
Magenta	0	1	1	0.41	−0.41	0.59	0.59	0.525	0.28
Blue	0	0	1	0.11	−0.11	−0.11	0.89	0.31	−0.32
Cyan	1	0	1	0.70	0.3	−0.7	0.3	−0.21	−0.60

[1] The quantities shown in the diagrams of this report are "phasors" as defined by AIEE-IRE. The use of the word "vector" does not create ambiguity in this paper, since no space values are present.

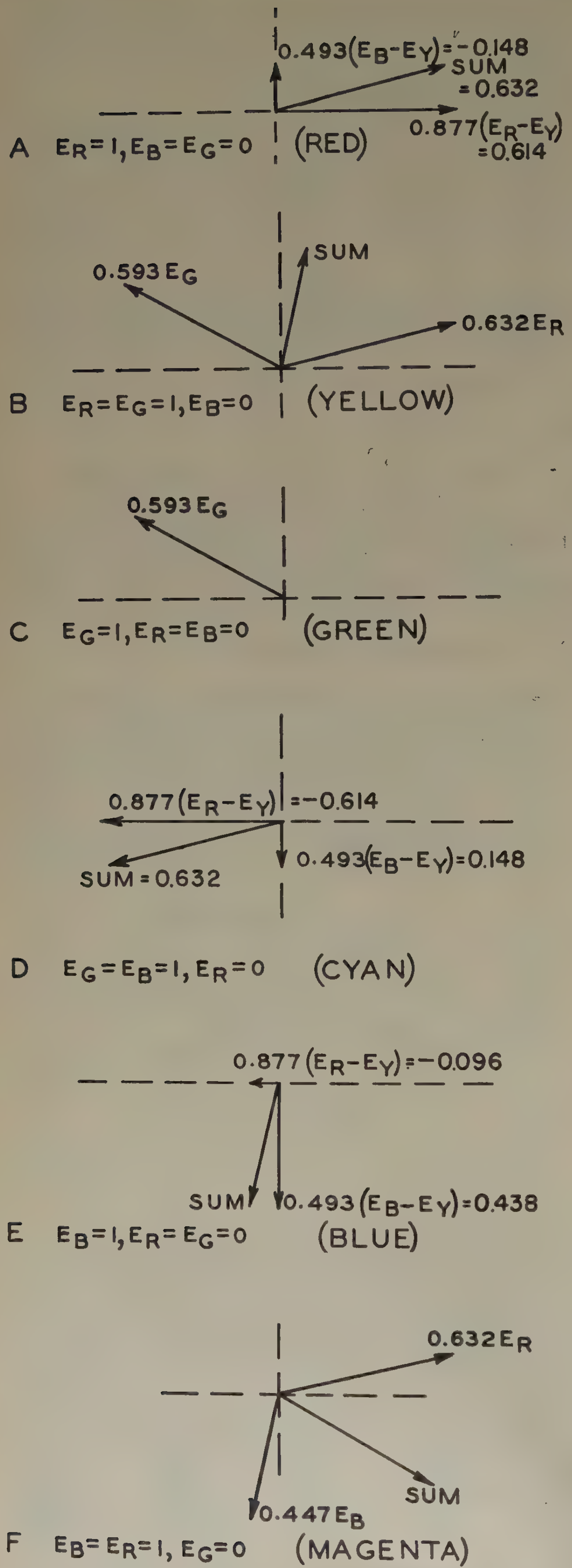

$0.493(E_B-E_Y)=-0.148$
SUM =0.632
$0.877(E_R-E_Y)$ =0.614
A $E_R=1, E_B=E_G=0$ (RED)
$0.593E_G$
SUM
$0.632E_R$
B $E_R=E_G=1, E_B=0$ (YELLOW)
$0.593E_G$
C $E_G=1, E_R=E_B=0$ (GREEN)
$0.877(E_R-E_Y)=-0.614$
$0.493(E_B-E_Y)=0.148$
SUM = 0.632
D $E_G=E_B=1, E_R=0$ (CYAN)
$0.877(E_R-E_Y)=-0.096$
SUM
$0.493(E_B-E_Y)=0.438$
E $E_B=1, E_R=E_G=0$ (BLUE)
$0.632E_R$
SUM
$0.447E_B$
F $E_B=E_R=1, E_G=0$ (MAGENTA)

Fig. 2

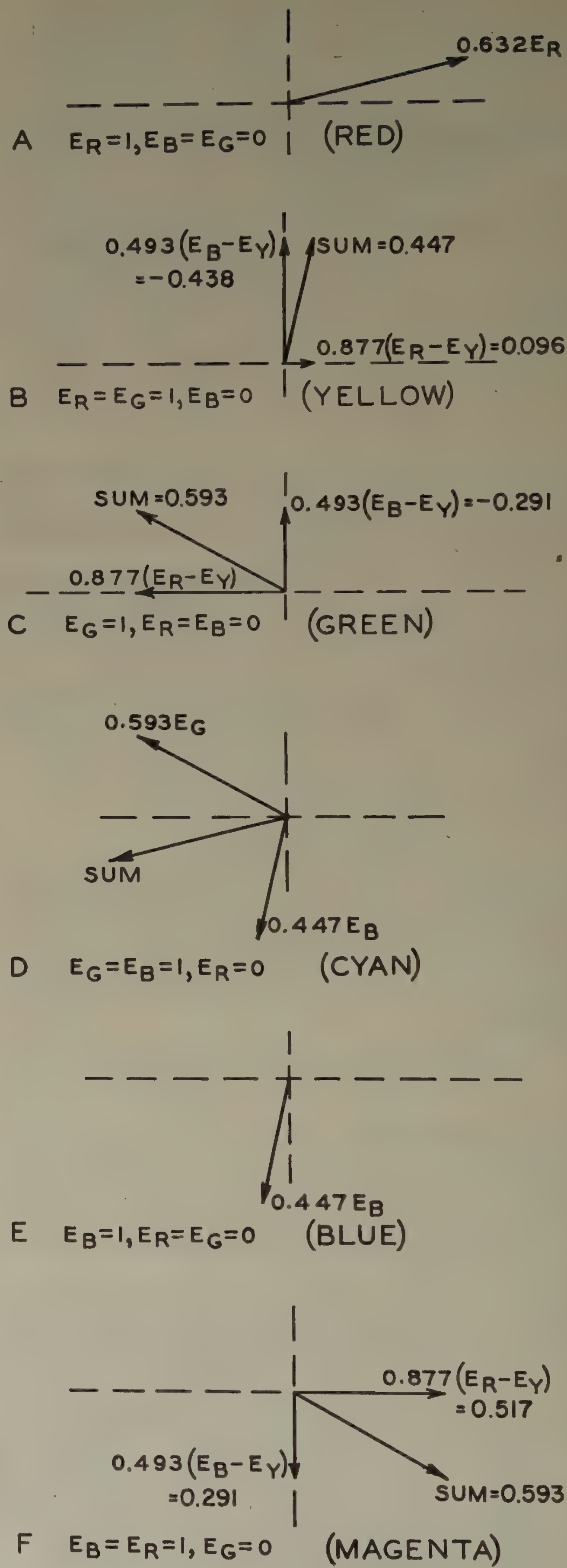

$0.632E_R$
A $E_R=1, E_B=E_G=0$ (RED)
$0.493(E_B-E_Y)$ =−0.438
SUM =0.447
$0.877(E_R-E_Y)=0.096$
B $E_R=E_G=1, E_B=0$ (YELLOW)
SUM =0.593
$0.493(E_B-E_Y)=-0.291$
$0.877(E_R-E_Y)$
C $E_G=1, E_R=E_B=0$ (GREEN)
$0.593E_G$
SUM
$0.447E_B$
D $E_G=E_B=1, E_R=0$ (CYAN)
$0.447E_B$
E $E_B=1, E_R=E_G=0$ (BLUE)
$0.877(E_R-E_Y)$ =0.517
$0.493(E_B-E_Y)$ =0.291
SUM=0.593
F $E_B=E_R=1, E_G=0$ (MAGENTA)

Fig. 4

ponents for a variety of signal conditions are shown in Figs. 4(a) to 4(f), together with the total carrier-color signal.

It may be observed that when $E_R=1$, and $E_B=E_G=0$, (8) reduces to

$$E_M = 0.3 + 0.632 \sin (\omega t - 256.5°) \tag{9}$$

which is in exact correspondence with (7).

The Color Picture Signal Specification in Terms of Three Color-Difference Signals

Equations (6) or (8) may be transformed to an equivalent form which uses all three color-difference terms. The resulting expression is

$$\begin{aligned} E_M = E_Y &+ 1.44(E_G - E_Y) \sin (\omega t - 123°) \\ &+ [0.41(E_B - E_Y) \\ &\quad - 0.48(E_R - E_Y)] \sin (\omega t - 33°) \end{aligned} \tag{10}$$

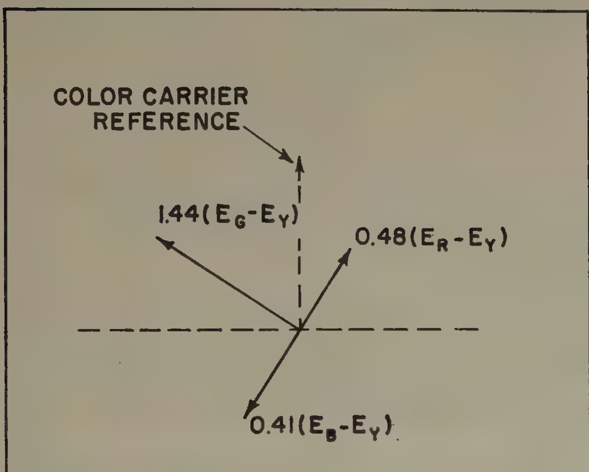


Fig. 5

Fig. 5 shows the subcarrier components of (10). The maximum value that each component may independently achieve is used in constructing this diagram. The actual values obtaining for these components for a variety of conditions, together with the sum of the components, are displayed in Fig. 6 on page 70.

It may be observed that the desired quantity (E_G-E_Y) may be obtained in the receiver by combining the carrier-color signal with $\sin (\omega t-123°)$ in a product demodulator. A similar application of $\sin (\omega t-33°)$ to the carrier-color signal in another product demodulator yields $0.41\ (E_B-E_Y)-0.48\ (E_R-E_Y)$. The remaining color-difference signals may be obtained by observing that

$$\begin{aligned} 1.695[0.41(E_B - E_Y) - 0.48(E_R - E_Y)] \\ - 1.59(E_G - E_Y) = E_B - E_Y \end{aligned}$$

and

$$\begin{aligned} -0.632[0.41(E_B - E_Y) - 0.48(E_R - E_Y)] \\ - 1.365(E_G - E_Y) = E_R - E_Y. \end{aligned}$$

The Color Picture Signal Specification in Terms of Symmetrical Components

A set of three unequal vectors disposed at arbitrary angles such that the vector sum is zero may be divided into a positive-sequence system and a negative-sequence system.[2] This method may be extended to the set of vectors of Figs. 1(b), and where the vectors are not in equilibrium. The resulting color picture signal specification is:

$$\begin{aligned} E_M = E_Y &+ 0.53E_B \sin (\omega t - 9°10') \\ &+ 0.53E_R \sin (\omega t - 9°10' - 240°) \\ &+ 0.53E_G \sin (\omega t - 9°10' - 120°) \\ &+ 0.11E_B \sin (\omega t - 175°) \\ &+ 0.11E_R \sin (\omega t - 175° - 120°) \\ &+ 0.11E_G \sin (\omega t - 175° - 240°) \end{aligned} \tag{11}$$

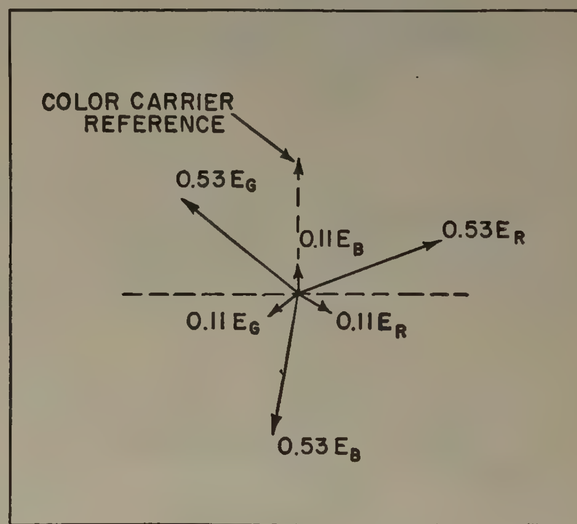


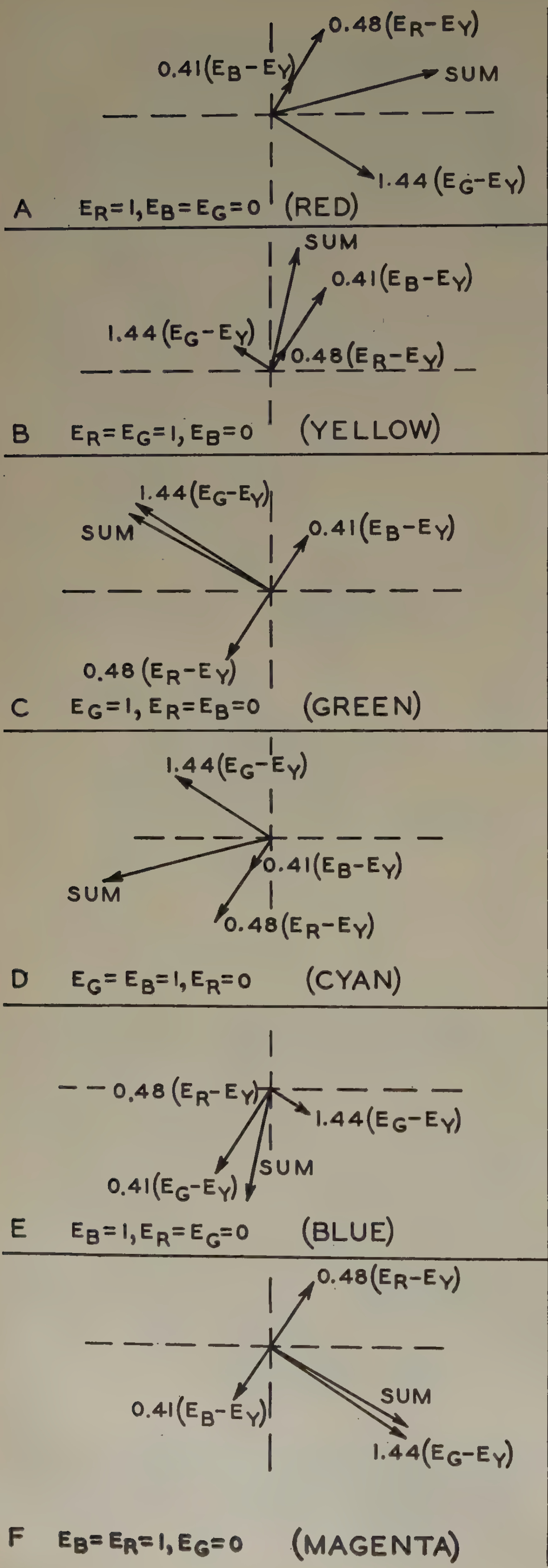
Fig. 7

The vector representation of the carrier-color portion of (8) is displayed in Fig. 7. The maximum value of each component is shown. It may be seen from this diagram that when the maximum values occur simultaneously $(E_G=E_R=E_B=1)$, the vector sum of each phase sequence is zero and the carrier-color signal disappears.

The individual phase sequences are similar to the carrier-color signal make-up used by RCA for experimental broadcasts as recently as the summer of 1951, where the three individual camera signals produced a set of three vectors spaced at 120 degrees one from another, with the gains so arranged that the three vectors were equal in magnitude when $E_G=E_R=E_B$, and the vector sum vanished for this condition.[3]

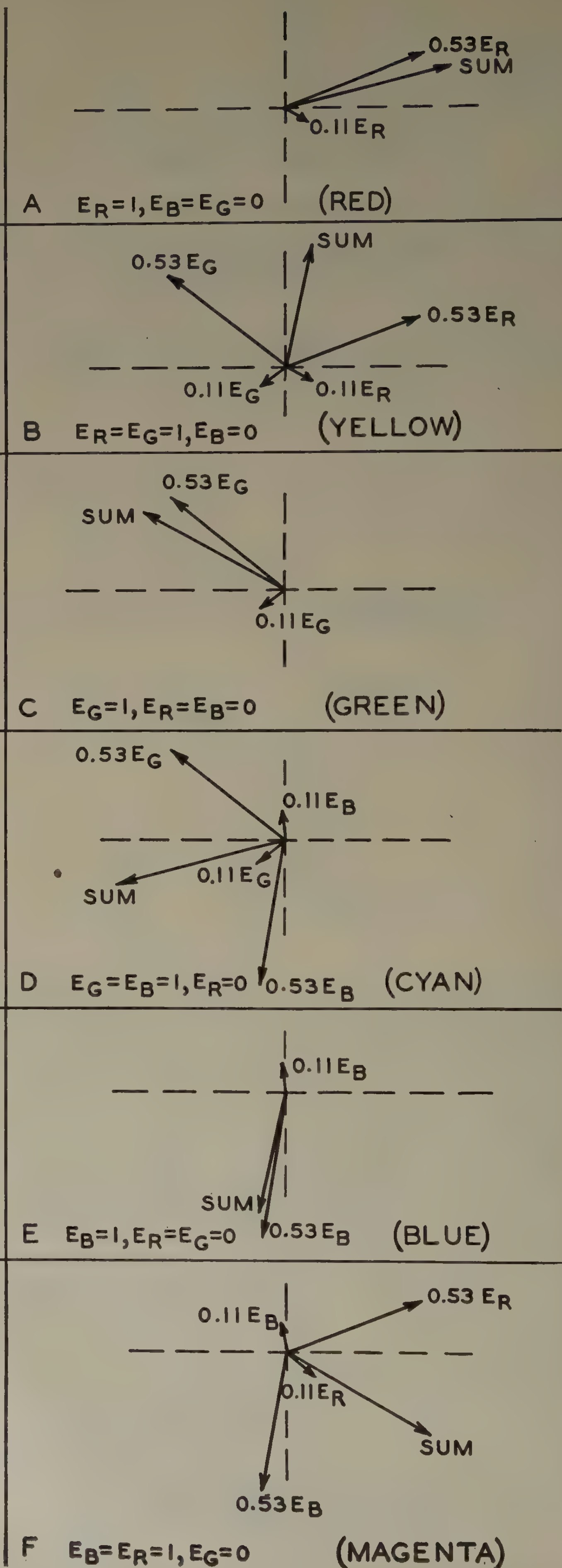
[2] C. F. Wagner and R. D. Evans, "Symmetrical Components as Applied to the Analysis of Unbalanced Electrical Circuits," McGraw-Hill Book Co., New York, N. Y., pp. 13–18; 1933.

[3] Report of the Ad Hoc Committee of the National Television System Committee on Color Television, NTSC-AHCT-75, Appendix C, (C-5), April 19, 1951.



$0.48(E_R-E_Y)$
$0.41(E_B-E_Y)$
SUM
$1.44(E_G-E_Y)$
A $E_R=1, E_B=E_G=0$ (RED)
SUM
$0.41(E_B-E_Y)$
$1.44(E_G-E_Y)$
$0.48(E_R-E_Y)$
B $E_R=E_G=1, E_B=0$ (YELLOW)
$1.44(E_G-E_Y)$
SUM
$0.41(E_B-E_Y)$
$0.48(E_R-E_Y)$
C $E_G=1, E_R=E_B=0$ (GREEN)
$1.44(E_G-E_Y)$
$0.41(E_B-E_Y)$
SUM
$0.48(E_R-E_Y)$
D $E_G=E_B=1, E_R=0$ (CYAN)
$0.48(E_R-E_Y)$
$1.44(E_G-E_Y)$
SUM
$0.41(E_G-E_Y)$
E $E_B=1, E_R=E_G=0$ (BLUE)
$0.48(E_R-E_Y)$
SUM
$0.41(E_B-E_Y)$
$1.44(E_G-E_Y)$
F $E_B=E_R=1, E_G=0$ (MAGENTA)

Fig. 6



$0.53E_R$
SUM
$0.11E_R$
A $E_R=1, E_B=E_G=0$ (RED)
SUM
$0.53E_G$
$0.53E_R$
$0.11E_G$
$0.11E_R$
B $E_R=E_G=1, E_B=0$ (YELLOW)
$0.53E_G$
SUM
$0.11E_G$
C $E_G=1, E_R=E_B=0$ (GREEN)
$0.53E_G$
$0.11E_B$
$0.11E_G$
SUM
D $E_G=E_B=1, E_R=0$ $0.53E_B$ (CYAN)
$0.11E_B$
SUM
E $E_B=1, E_R=E_G=0$ $0.53E_B$ (BLUE)
$0.53E_R$
$0.11E_B$
$0.11E_R$
SUM
$0.53E_B$
F $E_B=E_R=1, E_G=0$ (MAGENTA)

Fig. 8

The actual values obtaining for the components for a variety of signal conditions are shown in Figs. 8(a) to 8(f), together with the total carrier-color-signal.

The Color Picture Signal Specification When High-Frequency Components are Present

When the picture being scanned has changing brightness and the hue which includes high-frequency detail, the complete equation (1) must be used. The brightness term, E_Y, contains all frequency components. The quantity E_Q contains all components with frequencies less than approximately 500 kilocycles. The quantity E_I has all components with frequencies less than approximately 1,500 kilocycles. However, the "I" signal is divided into two distinct parts. The part with frequencies between zero and 500 kilocycles is transmitted double sideband. For frequencies between 500 and 1,500 kilocycles, the transmission is single-sideband. If a single-frequency video component of amplitude E_i, phase ϕ and frequency f_i (angular frequency β) exists, the last term of (1) becomes

$$-\tfrac{1}{2}E_i \sin[(\omega-\beta)t + 33° - \phi].$$

Conclusion

The mathematical representation of the NTSC signal has been presented in four ways, each yielding identical signals. These presentations are:

(1) In terms of two color-difference signals in quadrature. This presentation is important because the concept applies directly to a simple apparatus arrangement.

(2) In terms of the camera primary signals. The importance of this presentation lies in its similarity to past presentations of earlier forms of the color picture signal.

(3) In terms of three color-difference signals, to illustrate the variety of ways of presentation.

(4) In terms of symmetrical components, which again relates the NTSC signal specification to earlier forms of the color picture signal.

Transfer Characteristics in NTSC Color Television*

FRANK J. BINGLEY†, FELLOW, IRE

Summary—**The paper shows generalized curves of over-all system transfer characteristics measured from the luminance input to the luminance output; including the factors of background control settings at the receiver and of setup at the transmitter. These curves are shown for various pairs of power law characteristics at transmitter and receiver.**

The methods for translating transfer characteristics into colorimetric transfers are shown. The method is used to determine the colorimetric fidelity of the system, and illustrations are given in terms of CIE diagrams showing colorimetric departures for various background settings.

The paper discusses the relationship between television and photographic systems in respect to gamma.

Picture Tube Characteristic

Experiment shows that picture tubes have a power law type of characteristic. Like all vacuum tubes, there is a cutoff voltage (not always sharply defined) below which no anode current flows and no light output occurs.

Such a characteristic may be represented by

$$T_2 = a[(E_0 - E_c) + E)^{\gamma_2} \qquad (1)$$

where

T_2 is the light output of the tube which may be measured in lumens, or in total CIE tristimulus value, or any convenient and consistent unit. The subscript 2 is used to indicate that the tube is at the system output.

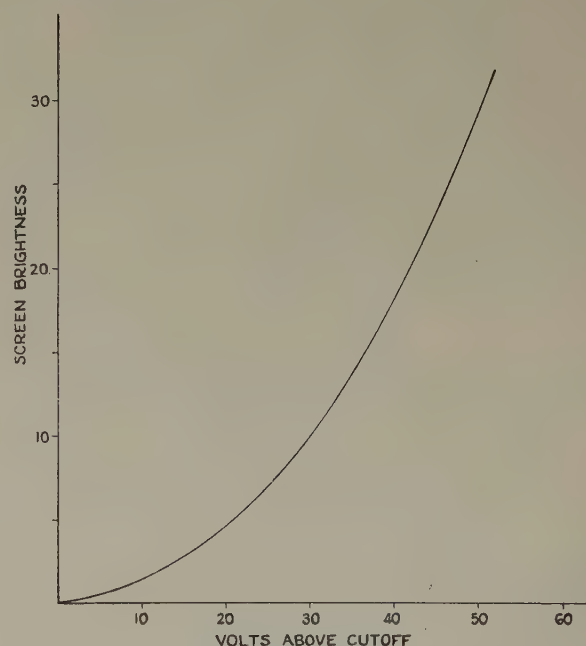


Fig. 1—Typical picture tube characteristic.

E_c is the cutoff voltage.

E_0 is the bias voltage added to the signal.

E is the signal voltage.

a and γ_2 are constants.

It should be noted that, in general, both E_c and E_0 are negative voltages. The equation expresses the fact that the output is a power function of the voltage *measured above cutoff*. A typical characteristic is illustrated in Fig. 1, above.

* Decimal classification: R583. NTSC Technical Monograph No. 12, reprinted by permission of the National Television System Committee from "Color System Analysis," Report of NTSC Panel 12.

† Philco Corp., Philadelphia, Pa.

Pickup Transfer Characteristics

At the camera, tristimulus value in the original scene is transformed into voltage output. Anticipating the power law characteristic of the tube, the voltage transfer at the camera may also be power law. In particular, it may be a power law exactly inverse to that of the picture tube, so that input tristimulus values are reproduced in exact ratio to the original. In general, it may be a power law with an index such that the product of input and output indices is less than or greater than unity; this will result in contrast reduction or enhancement.

Let it be assumed that the camera transfer characteristic is represented by the equation

$$E = c + bT_1^{\gamma_1} \tag{2}$$

where c is a constant voltage usually referred to as "setup"; and where b is a constant relating tristimulus value to voltage. The gamma index at the transmitter is γ_1, the separate symbol being used to emphasize that it is not necessarily inverse to that at the receiver.

Over-all System Characteristic

The above equations can be used to derive the over-all characteristic by eliminating the signal voltage E between them. When this is done there results

$$\begin{aligned} T_2 &= a[(E_0 - E_c) + c + bT_1^{\gamma_1}]^{\gamma_2} \\ &= a[(E_0 - E_c + c) + bT_1^{\gamma_1}]^{\gamma_2}. \end{aligned} \tag{3}$$

Note that the setup voltage c may be absorbed in the cutoff and bias voltages at the picture tube. The first step towards accurate rendition is to adjust either the setup voltage "c" at the transmitter, or the bias voltage E_0 at the receiver, so that the sum $E_0 - E_c + c$ vanishes. Then the transfer equation becomes

$$T_2 = ab^{\gamma_2}T_1. \tag{4}$$

There are now two further steps which can be taken to obtain precise duplication of the input values at the output. These steps are stated by the following equations

$$ab^{\gamma_2} = 1 \tag{5}$$

$$\gamma_1\gamma_2 = 1. \tag{6}$$

When both of these have been satisfied, the reproduction is exact. It is not always necessary, or desirable, or possible to have exact rendition, so that the more general condition will be studied further. In the following derivation it is assumed that $(E_0 - E_c + c)$ is not zero.

Equation (3) may be rearranged by dividing both sides by $(E_0 - E_c + c)^{\gamma_2}$; there then results

$$\frac{T_2}{a(E_0 - E_c + c)^{\gamma_2}} = \left[1 + \frac{b}{E_0 - E_c + c} T_1^{\gamma_1}\right]^{\gamma_2}. \tag{7}$$

If

$$x = \left[\frac{b}{E_0 - E_c + c}\right]^{1/\gamma_1} T_1$$

and

$$y = \frac{T_2}{a(E_0 - E_c + c)^{\gamma_2}}$$

then (7) becomes

$$y = (1 + x^{\gamma_1})^{\gamma_2}. \tag{8}$$

For large values of x this approaches

$$y = x^{\gamma_1\gamma_2} \tag{9}$$

and if $\gamma_1\gamma_2 = 1$ it becomes

$$y = x. \tag{10}$$

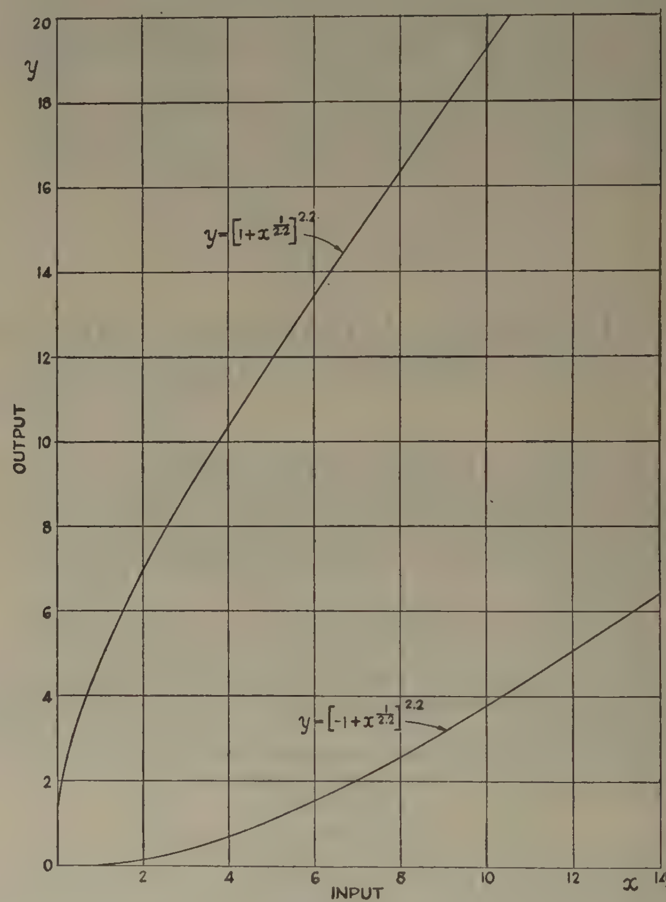


Fig.

By assuming values for γ_1 and γ_2 it becomes possible to plot curves showing the transfer characteristic. Fig. 2 shows a plot for

$$\gamma_1 = \frac{1}{2.2} \qquad \gamma_2 = 2.2.$$

Note that because of the nonintegral power implied by general values of γ_1 and γ_2, $(E_0 - E_c + c)$ must be assumed to be positive. If it is not positive, then the substitution suggested above must be replaced by

$$x = \left[\frac{b}{-(E_0 - E_c + c)}\right]^{1/\gamma_1} T_1$$

$$y = \frac{T_2}{a[-(E_0 - E_c + c)]^{\gamma_2}}$$

and the equation becomes

$$v = (-1 + x^{\gamma_1})^{\gamma_2}. \tag{11}$$

This is the second plot shown on Fig. 2, again assuming

$$\gamma_1 = \frac{1}{2.2} \qquad \gamma_2 = 2.2.$$

It is seen that large values of x and y result in a plot approaching the straight line $y=x$. These large values are achieved by making E_0-E_c+c small. These curves are truly universal, merely requiring the scales to be determined by inserting values of the constants a and b and of the net "bias offset" E_0-E_c+c.

In order to compress the wide range of values encountered, these curves may be replotted on log-log paper. This has been done in Fig. 3(a).

Perceptibility

Consider a range of values T_A to T_B in the input, and T_C to T_D in the output. Suppose that the input T_1 is a number of steps of perceptibility above the lowest value T_A, such number being proportionate to the number which output T_2 is above lowest T_C in its range.

Measure everything from T_A in the input range, and from T_C in the output range. Let δ be the least perceptible change, assumed a small percentage of the initial value, as in the Weber-Fechner law which has been shown to apply to the visual process.

Then

$$(1+\delta)\Delta n = 1 + \frac{\Delta T}{T}$$

or

$$\Delta n \log_e (1+\delta) = \log_e \left[1 + \frac{\Delta T}{T_{T_1}}\right]$$

$$\delta \Delta n = \frac{\Delta T}{T_{T_1}} \qquad [\log_e (1+\delta) = \delta \text{ if } \delta \text{ small})]$$

$$n_1\delta = \int_{T_A} \frac{\Delta T}{T} \qquad n_1 = \text{no. of shades } T_1 \text{ is above } T_a$$

$$= \log_e \frac{T_1}{T_A}$$

$$n_1 = \frac{1}{\delta} \log_e \frac{T_1}{T_A}.$$

Similarly n_2, the number of shades that T_2 is above its lower reference T_C is given by

$$n_2 = \frac{1}{\delta} \log_e \frac{T_2}{T_C}.$$

If we want n_2 to be always proportional to n_1 (i.e. the distribution of perceptibility of the output tracks that of the input, even if the over-all range is compressed or expanded) then

$$Sn_1 = n_2 \qquad S = \text{a constant}$$

thus

$$\frac{S}{\delta} \log_e \frac{T_1}{T_A} = \frac{1}{\delta} \log_e \frac{T_2}{T_C}$$

$$\frac{T_2}{T_C} = \left(\frac{T_1}{T_A}\right)^S.$$

The upper ends of the input and output ranges would correspond if

$$\left(\frac{T_B}{T_A}\right)^S = \frac{T_D}{T_C}$$

$$S = \frac{\log \frac{T_D}{T_C}}{\log \frac{T_B}{T_A}}.$$

Thus if we have an input range T_A to T_B (defining an input contrast ratio $T_B/T_A = C_1$) and an output range T_C to T_D (defining an output contrast ratio $T_D/T_C = C_2$); and if we want shades of perceptibility in the reproduction between parts of the image to bear a constant ratio to the shades of reproduction of the same parts in the original, the constant of proportionality being S, then the enhancement of contrast range in the reproduction S is given by

$$S = \frac{\log C_2}{\log C_1}.$$

A power law relation between input and output fulfills the condition of uniform contrast enhancement (or degradation, if $S<1$).

The output-input relation then is

$$T_2 = \frac{T_c}{T_A^s} T_1^S.$$

Some numerical idea of contrast range may be obtained by assigning a value to δ. The small area contrast sensitivity of the eye is about 2 per cent; that is to say, two small areas placed side by side can just be distinguished to have differing luminances if one has a value 2 per cent higher than the other. This can be used to find the number of sensation units (or perceptibility units) in a given range of luminance values. For if T_B and T_A represent, as before, the upper and lower boundaries of the contrast range, then

$$1.02^n = \frac{T_B}{T_A} = C$$

where n is the number of sensation units, and C is the contrast range.

This equation leads to the following:

$$n \log 1.02 = \log C$$

$$n = \frac{\log C}{\log 1.02}.$$

For a contrast ratio of 30 this becomes

$$n_{30} = \frac{\log 30}{\log 1.02} = \frac{1.4771}{.0086} = 172.$$

range is $\log \rho_1/\rho_2$, ρ_1 being the reflection coefficient in the lightest parts of the print, ρ_2 that in the darkest). When such printing paper is used to reproduce a scene of average contrast range of 160, it is evident that some compression of over-all contrast must be tolerated, because $\log_{10} 160 = 2.2$.

Logarithmic units are used almost exclusively in photographic practice to represent tone rendition. This has several advantages, among which are: (a) equal distances along a logarithmic plot represent equal perceptibility steps; and (b) wide ranges of values are thereby more readily represented. These advantages are also equally significant in the case of television.

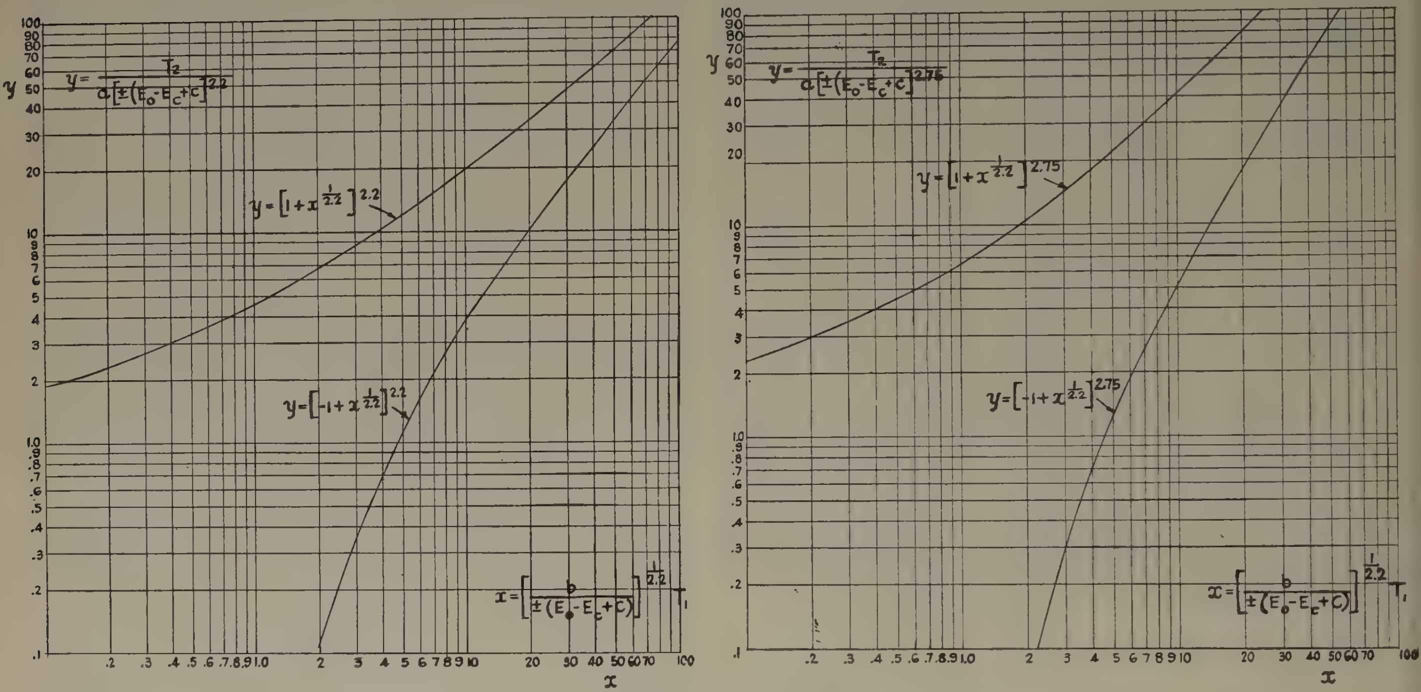


Fig. 3(a)—Universal transfer curves. (b) Universal transfer curves.

So that, if suitably arranged so as to utilize the full contrast sensitivity of the eye, a picture having a contrast ratio of 30 (a realistic value for a photographic print) would contain 172 just perceptible units.

Contrast Range

There has, naturally, been considerable investigation of this matter carried out by workers in the photographic field. One of the most extensive investigations explored the range of exterior scenes (reference 1). By examining the contrast range of one hundred and twenty-six scenes, it was found that the average range was 160. The minimum figure was 20, and the maximum 900. For interior scenes, it is reported that sets in motion picture and portrait studios rarely exceed a brightness range of 150.

The available density range of glossy photographic printing paper is about 1.8 (where density is defined as $\log_{10}\rho$, ρ being the reflection coefficient; so the density

The logarithmic curves in Fig. 3(a) have a universal character. The upper curve shows the effect of high setup in the signal, or of operation of the picture tube at high background control setting. The contrast range is seen to be compressed, particularly in the shadows. On the other hand, the lower curve shows the effect of too low a background setting at the receiver. Contrast ratio in this case is enhanced, the greatest effect being in the shadows. The actual placement of the input signal along the scale of abscissas is determined by the amount of bias offset (i.e., by the value of $E_0 - E_c + c$). A small value of bias offset will result in large values of x (without, of course, altering the contrast ratio) so that the signal will fall in that region where the curve is almost straight and there will be little distortion.

The curves shown in Fig. 3(a) are based upon exactly inverse gamma indexes, namely 1/2.2 and 2.2 respectively.

Similar curves can be drawn for noninverse characteristics by inserting appropriate selected values of γ_1, and γ_2 in (8) and (11). As an illustration of this possibility, Fig. 3(b) is presented. This shows universal transfer curves drawn for $\gamma_1=1/2.2$ and $\gamma_2=2.75$. As before, the upper curve represents a positive bias offset, the lower curve a negative offset.

Calculation of Colorimetric Distortion

In the case of a television system where red, green and blue information passes through independent channels each having an individual transfer characteristic, the universal curves given enable colorimetric distortion to be plotted.

In the general case, all three over-all gamma characteristics will be different both in respect of over-all gamma product and in respect of bias offset. If the appropriate curves and bias offsets are known, however, (as well as the usual transmitter and receiver constants a and b) then the outputs in each of the channels can be read from the corresponding curves. Of course, the voltages of the input signals must be expressed as the logarithm of their ratio to a reference signal. The effect of bias offset is to slide the whole input signal along the abscissa, moving it away from the origin as the bias offset decreases. The effect of changing the transmitter constant (that is, the value of "b" in [7]) is also to slide the input signal along the abscissa axis. On the other hand, the effect of changing the receiver gain factor "a" is to alter the tristimulus output by a constant scale factor throughout its range. Then, if we imagined there to be an auxiliary scale of tristimulus values placed parallel to the ordinate axis from which tristimulus values were read directly (of course it would be a logarithmic scale), this scale would move up or down parallel to the ordinate as the gain was varied.

As a specific illustration, consider a camera having an input chromaticity corresponding to illuminant C so that the three tristimulus values R_1G_1 and B_1 are equal. These quantities are then each converted by the system into voltages, setup is added, and they are passed through the transfer characteristics. Assume for simplicity that the gamma indexes in all three channels are 1/2.2 at the transmitter and 2.2 at the receiver. Because the bias offsets E_0-E_c+c will be in general different for the three channels, as well as the transmitter constant b, the tristimulus values R_1B_1 and G_1 will be represented by different values of x (for example, for the red channel $x=7$, green $x=15$, blue $x=10$). If all the bias offsets are positive, then upper Fig. 3(a) curve applies. Reading corresponding values of y we find that, for the red channel $y_{\text{RED}}=13.5$; for the green channel $y_{\text{GREEN}}=27$; and $y_{\text{BLUE}}=20$. Then respective tristimulus outputs are:

$$R_2 = a_R[(E_{OR} - E_{CR} + C_R)^{\gamma_2}]y_{\text{RED}}$$
$$= a_R[(E_{OR} - E_{CR} + C_R)^{\gamma_2}]13.5$$
$$G_2 = a_G[(E_{OG} - E_{CG} + C_G)^{\gamma_2}]27$$
$$B_2 = a_B[(E_{OB} - E_{CB} + C_B)^{\gamma_2}]20$$

where the second subscripts, R, G and B, used on the right hand side are intended to distinguish values in the red, green, and blue channels respectively.

Obviously, we can make $R_2=G_2=B_2$ by setting the channel gains a_Ra_G and a_B to suitable values. Thus white balance can be achieved for the particular input levels R_1G_1 and B_1. However, if the input level is reduced (still maintaining the chromaticity at illuminant "C"), the system will not stay in balance with the same receiver gain settings.

The regime for adjusting white balance so that it holds throughout the complete range of luminance values, is to adjust, first, the receiver background controls in each of the channels until the constants $b/(E_0-E_c+c)$ are equal in all three channels. Then when illuminant C is transmitted, not only is $R_1=G_1=B_1$, but also $x_{\text{RED}}=x_{\text{GREEN}}=x_{\text{BLUE}}$; and this holds for all levels of input. Turning now to the output, the three corresponding values of y are equal, so that it is only necessary to adjust the three channel gains at the receiver until $R_2=G_2=B_2$. The balance will now be automatically maintained at all input levels.

For chromaticities other than illuminant C, the ratios of $R_1:G_1:B_1$ and of $R_2:G_2:B_2$ will not be alike, so that colorimetric distortion occurs. This arises because the curve is not a straight line, but the situation can be improved to any required degree by making the bias offset in each channel approach zero, so that we are working high up on the curve (large values of x) where the curve asymptotically approaches a straight line.

Plots of color distortion can be made over the chromaticity diagram by first postulating the transfer characteristics and the operating point. Then the values $R_2G_2B_2$ corresponding to inputs $R_1G_1B_1$ can be found from the universal gamma curves in the manner previously described. From these can be determined the values of

$$r_2 = \frac{R_2}{R_2 + G_2 + B_2}$$

$$g_2 = \frac{G_2}{R_2 + G_2 + B_2}$$

$$b_2 = \frac{B_2}{R_2 + G_2 + B_2}$$

any two of which are sufficient to determine the output chromaticity, and of

$$r_1 = \frac{R_1}{R_1 + G_1 + B_1}$$

$$g_1 = \frac{G_1}{R_1 + G_1 + B_1}$$

$$b_1 = \frac{B_1}{R_1 + G_1 + B_1}$$

any two of which will determine input chromaticity.

In order to plot the input and output on a chromaticity diagram, use may be made of Fig. 4, which shows a CIE diagram with the NTSC primary triangle drawn on it, together with a grid marked in values of r, g and b. This grid can be used to make a direct plot of input and output chromaticities.

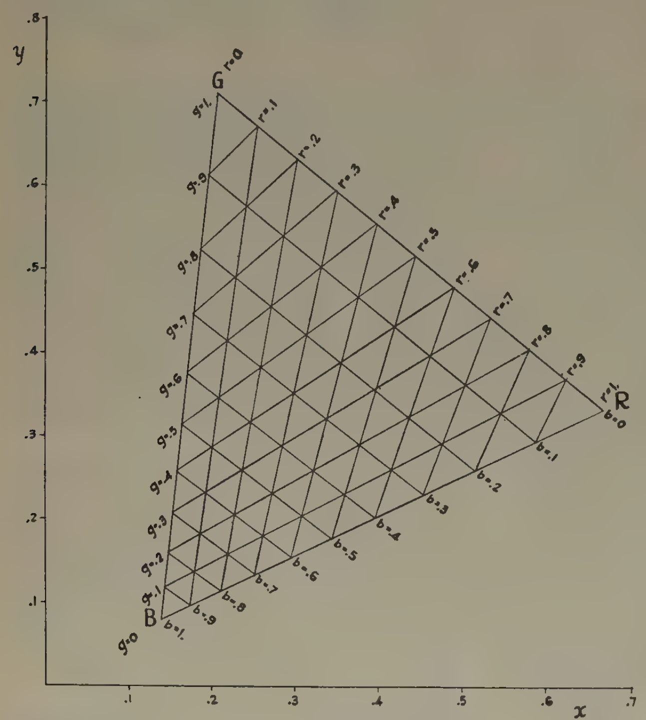


Fig. 4

Effect of Various Forms of Gamma Correction on Television Signal

The NTSC color signal consists of a monochrome signal and a chrominance signal. The former signal conveys essentially luminance information, the latter, chrominance. Various methods of composing signals of this type have been proposed. They all are of the general type expressed by the equation

$$E_S = E_M + E_C \cos \overline{\omega t + \phi}.$$

It is convenient to express the signal in normalized form by the equation

$$\frac{E_S}{E_M} = 1 + \frac{E_C}{E_M} \cos \overline{\omega t + \phi}$$

where now E_C/E_M may be called the normalized color carrier amplitude.

Various forms of signal makeup have been considered. They may be classified as follows, with respect to their monochrome component:

1) Monochrome signal proportional directly to luminance, that is $E_M = E_Y = KY$.
2) Monochrome signal proportional to luminance raised to the power $1/\gamma$; that is

$$E_M = E_Y{}^{1/\gamma} = K^{1/\gamma} Y^{1/\gamma}.$$

3) Monochrome signal largely representative of gamma corrected luminance; being of the form

$$E_M = E_Y' = sE_R' + tE_G' + uE_B'$$

where s, t and u are the luminance contribution coefficients (2) and where

$$E_R' = KR^{1/\gamma} E_G' = KG^{1/\gamma}\ E_B' = KB^{1/\gamma}.$$

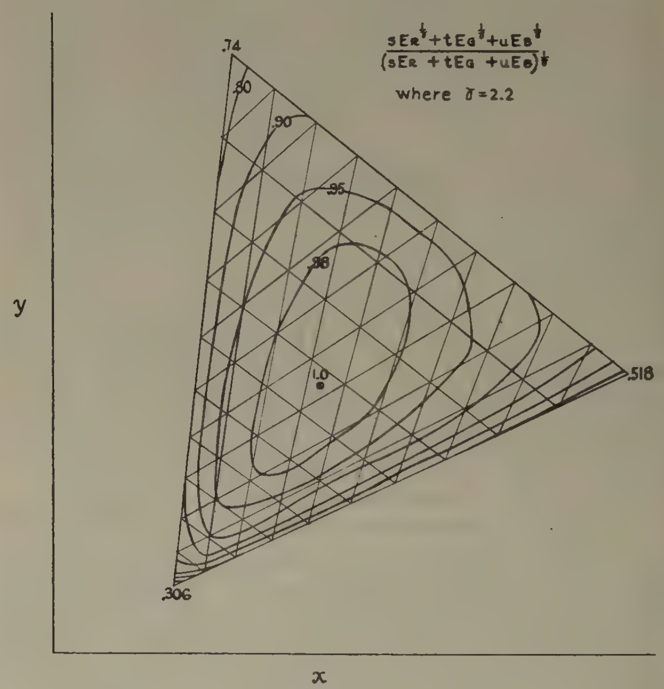


Fig. 5

4) Monochrome signal of the form

$$E_M = E_Y' + E_A$$

where E_A is an additional component of the monochrome signal which acts to improve the luminance fidelity of detail in the reproduced picture.
5) Color carrier made up of vectors linearly proportional to $R-Y$ and $B-Y$.
6) Color carrier made up of vectors proportional to $E_R' - E_Y'$ and $E_B' - E_Y'$ (3).

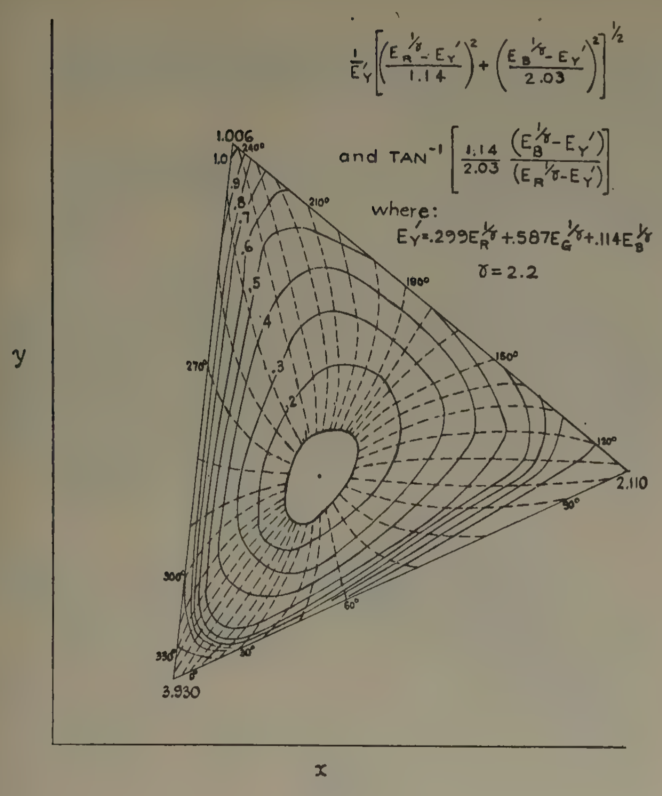


Fig. 6

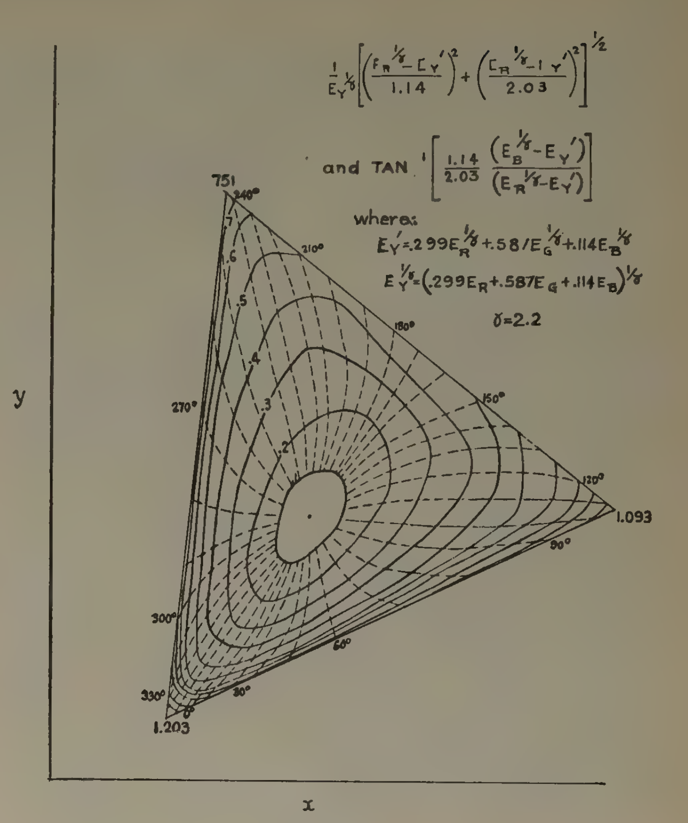


Fig. 7

Typical equations for television signals of these types are

$$(1)\quad E_S = E_Y' + \frac{E_R' - E_Y'}{1.14}\cos wt + \frac{E_B' - E_y'}{2.03}\sin wt$$

$$(2)\quad E_S = E_Y^{1/\gamma} + \frac{E_R' - E_Y'}{1.14}\cos wt + \frac{E_B' - E_Y'}{2.03}\sin wt$$

$$(3)\quad E_S = E_Y^{1/\gamma} + \frac{E_Y^{1/\gamma}}{\gamma}\,\frac{E_R - E_Y}{1.14}\cos wt + \frac{E_B - E_Y}{2.03}\sin wt.$$

The monochrome signals exhibit differences. While $E_Y^{1/\gamma}$ contains complete and accurate information about luminance, E_Y' does not. It has been shown (4) that E_Y' conveys a portion of the total luminance which represents 100% for white objects, but falls off gradually as saturation increases. This is shown in Fig. 5.

It has been shown (2) that plots can be made of normalized color carrier amplitude and phase on a chromaticity diagram, in such a way that normalized color carrier amplitude represents saturation, and phase represents hue. Plots for signals (1) (2) and (3) are shown in Figs. 6, 7 and 8.

These signal maps show the differences in video signal arising from different handling of the gamma operation. All are identical near white, but depart increasingly one from the other as color saturation is increased.

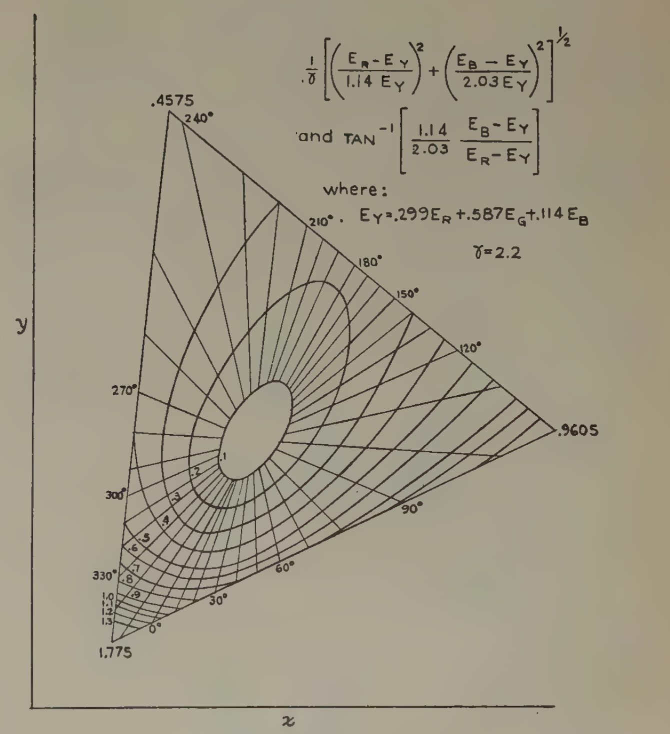


Fig. 8

Similar maps for $\gamma = 2.75$ are shown in Figs. 9, 10, 11 and 12, which appear on the following page. These will enable a comparison to be made with the corresponding figures for $\gamma = 2.2$.

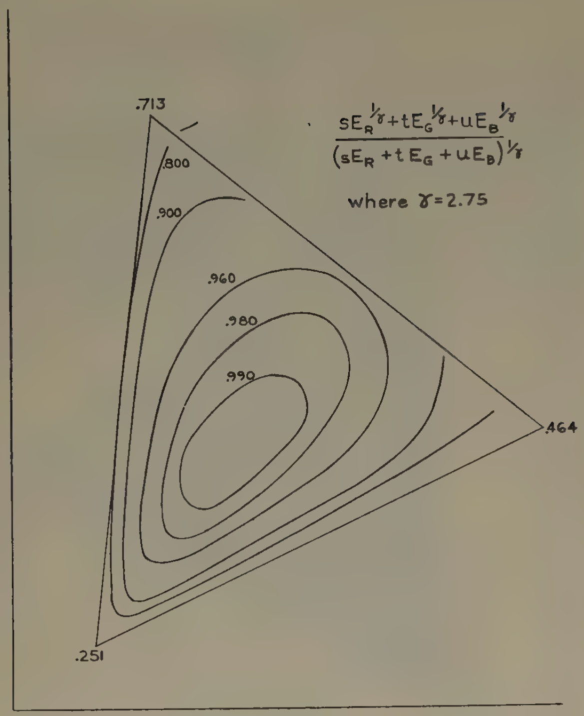


Fig. 9

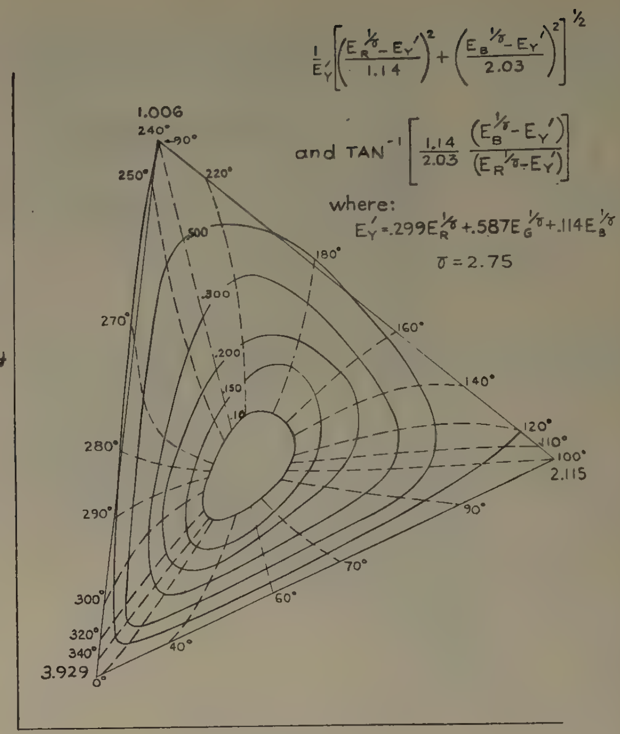


Fig. 10

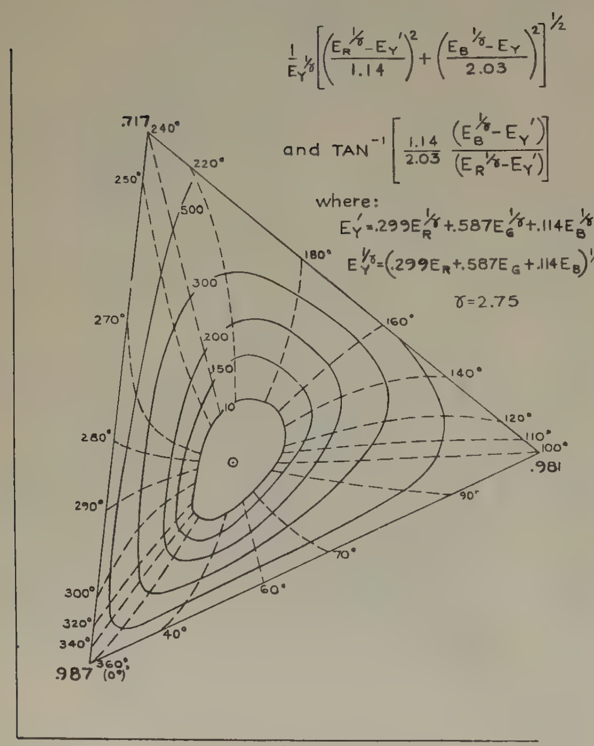


Fig. 11

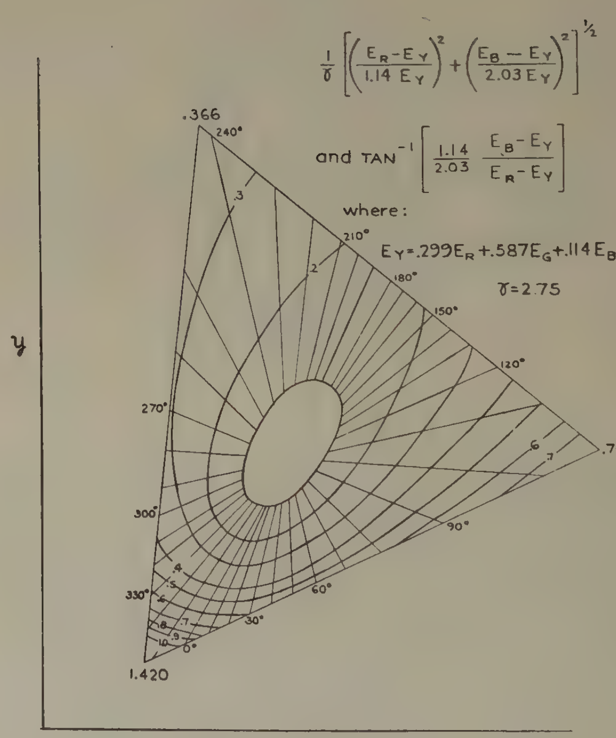


Fig. 12

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Choice of Chrominance Subcarrier Frequency in the NTSC Standards*

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Summary—**There are a number of considerations which lead to the final choice of the chrominance subcarrier frequency in the NTSC signal. In addition to the considerations given elsewhere[1] it is also desirable to minimize the visibility of the beats between the sound carrier and the chrominance subcarrier. This requires a slight alteration of the nominal field and line rates over those used in monochrome television.**

Introduction

There are a number of factors which influence the choice of the chrominance subcarrier frequency in the National Television System Committee Standards. They are governed primarily by interference effects by and to the chrominance signal in both existing monochrome, as well as color television receivers. In this paper are discussed the reasons for the final choice of the subcarrier frequency as well as its tolerances. In addition, the resulting choice of field and line frequencies as well as sound carrier-video carrier frequency separation are covered.

Approximate Choice of Subcarrier Frequency

It is desirable that the subcarrier frequency be chosen high enough to minimize interference with the luminance signal. Thus, in an existing monochrome receiver, any dot structure resulting from the subcarrier will not only be as fine as possible, but it will also be reduced by any attenuation in the receiver at the chrominance subcarrier frequency. On the other hand, the chrominance subcarrier frequency must be low enough so as to permit the upper side-bands of the carrier chrominance signal to fall within the useful video band. As explained by Brown and others,[2–5] the spectrum of the carrier chrominance signal needs to extend only to frequencies lying approximately 0.6 megacycle above the subcarrier. Since it is practical to obtain video bandwidths of approximately 4.2 mc in transmitters and receivers, the subcarrier frequency may be chosen as high as 3.6 mc.

Closer Selection of Subcarrier Frequency

The choice of a subcarrier frequency is also dictated by the "frequency interleaving" principle. This has been discussed at length elsewhere by the author.[1] It was shown in that paper that it is desirable to choose a frequency which is an odd multiple of one-half the line rate; further, that this multiple have small (odd) factors. Accordingly, it may be seen that if we choose the multiple 455, having the factors 13, 7, and 5, one would obtain a subcarrier frequency of 3.583125 mc.

Effect of Sound Carrier Interference

This frequency would prove quite satisfactory were it not for a further consideration, involving the presence of the sound carrier. In some monochrome receivers now in use, there may be insufficient attenuation of the sound carrier to prevent an objectionable 0.9-mc signal, resulting from the beat between the sound carrier and the chrominance subcarrier. Experiments have shown[6] that this beat signal is much less objectionable if it is an odd multiple of one-half the line rate, because of the "frequency interleaving" effect previously referred to. This requires that the sound and video carriers be separated by an amount approximately equal to a multiple of the line rate (i.e., an even multiple of one-half the line rate). This means that the beat between the visual and aural carriers is *not* interleaved. Its visibility, however, is so low anyway, because of 4.5-mc attenuation and the fine structure of the pattern, that no difficulty is encountered. Because of the frequency modulation of the sound carrier, the beat between it and the chrominance subcarrier will likewise be frequency modulated, and therefore, be "interleaved" only on the average. There is, nevertheless, a definite reduction in beat visibility.[6]

It is easily computed that there are harmonics of 15.75 kilocycles at 4.48875 and 4.5045 mc, corresponding to the 285*th* and 286*th* multiples, respectively. The latter figure is nearest to the proper nominal value;

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† General Electric Co., Syracuse, N. Y.

[1] I. C. Abrahams, "The 'Frequency Interleaving' Principle in the NTSC Standards," NTSC Technical Monograph No. 3; and Proc. I.R.E., pp. 81–83; this issue.

[2] G. H. Brown, "Choice of Axes and Bandwidths for the Chrominance Signals in NTSC Color Television," NTSC Technical Monograph No. 14; and Proc. I.R.E., pp. 58, 59; this issue.

[3] P. W. Howells, "A Proposal for a Modification of the Chrominance Signal Specification," NTSC Document P13-289, August, 1952.

[4] W. F. Bailey and C. J. Hirsch, "Quadrature Crosstalk in NTSC Color Television," NTSC Technical Monograph No. 2-A; and Proc. I.R.E., pp. 84–90; this issue.

[5] RCA Laboratories, "Tests Relating to the Choice of Narrow and Wide-band Components for a Balanced Color Gamut System," NTSC Document P-13-286, October 19, 1952.

[6] Report of Subcommittee No. 8, Panel 13, NTSC, on "Visibility of Beat-note between Sound and Color Subcarrier," August, 1952.

nevertheless, it would be unsatisfactory to move the sound carrier by the required 4,500 cycles, lest some of the existing monochrome sets be unable to obtain proper sound reception. The sound carrier has, therefore, been left at its monochrome value; i.e., separated from the video carrier by 4.5 mc. In order to obtain "frequency interleaving" with the chrominance subcarrier, it is, therefore, necessary to move the latter. This, in turn, necessitates moving the line and field rates by the same percentage, in order to maintain "frequency interleaving."

Choice of Exact Frequencies

The new frequencies were, therefore, chosen by defining the sound-carrier separation of 4.5 mc as being the 286*th* harmonic of the new line rate. This leads to a horizontal frequency of

$$f_l = \frac{4.5 \times 10^6}{286} \text{ cps} \tag{1}$$

$$= 15,734.26 \text{ cps.}$$

Since there will still be 525 lines per frame, the new field frequency then becomes

$$f_f = \frac{f_l}{525/2}$$

$$= 59.94 \text{ cps.} \tag{2}$$

The subcarrier frequency is given by

$$f_s = \frac{455}{2} \times f_l, \tag{3}$$

as before. In view of (1),

$$f_s = \frac{455}{2} \times \frac{4.5 \times 10}{286} \text{ cps}$$

$$= 3.579545 \text{ mc.}$$

It should be noted that these values of f_l and f_f are only 0.1 per cent removed from the nominal values now used for monochrome, which is well within the tolerance of 1.0 per cent allowed for such operation.

The values of f_l and f_f given above do not permit synchronous operation with the power line. As will be seen later, the tolerances would not permit such operation anyway. With the advent of network and other remote operations, power-line synchronous operation is of little value or necessity, in any case.

It should be noted that in order to reduce further the beat between the sound carrier and the color subcarrier, the maximum aural power is limited to 70 per cent of the peak visual power. It has been found in monochrome practice that this is sufficient aural power for good reception.[6]

Tolerances

The tolerance on the subcarrier frequency has been set at ±0.0003 per cent, or about ±10 cps. The rate of change of frequency of the subcarrier has been set at not more than 1/10 cps per second. These tolerances have been chosen in order to facilitate synchronization of the subcarrier at the receiver. Thus, for example, the use of crystal oscillators or filters is made easier.

In addition, the sound-carrier–picture-carrier separation is required to be held to within ±1,000 cps. This is in order to maintain as much as possible the advantages of the "frequency interleaved" beat between the sound carrier and the chrominance subcarrier.

The "Frequency Interleaving" Principle in the NTSC Standards*

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Summary—**In the NTSC signal, in order to achieve minimum interference by the chrominance signal to the luminance information, it is necessary that the subcarrier frequency have a special relationship to the field and line frequencies. This paper discusses the general conditions which are necessary as well as the practical considerations leading to a choice of the subcarrier frequency in the NTSC standards.**

Introduction

One of the principal objectives of the National Television System Committee's standards is the transmission of a maximum amount of useful information in the allotted spectrum space. This is accomplished in two ways: first, by transmitting only that information which can be usefully assimilated by the human eye; and second, by so packaging the information which *is* to be transmitted as to assure the most efficient utilization of the spectrum space. This paper is concerned with a discussion of the second method of spectrum conservation, by the use of frequency interleaving.

Scanning Method and Frequency Distribution of Still Pictures

To arrive at a possible solution to the problem of spectrum economy it is first necessary to examine and analyze the frequency distribution of the signal to be transmitted. As is well known, in the case of television a process of scanning of the image is used, to change from a two-dimensional system of co-ordinates to one having a single dimension. The resulting function can then be transmitted as a variation of voltage with respect to time. The scanning is done by means of a series of parallel lines, 525 in number in the present standards. A system of "interlaced" scanning is employed; i.e., the image is scanned by only half of the lines at first, whereupon the remaining lines are laid down in between the first lines. The whole process is repeated thirty times per second. It can be shown that this scanning pattern can be achieved by a constant velocity motion of the aperture (excluding the retrace) at a rate of 15,750 times per second in the horizontal direction (referred to as the "line frequency"), and a rate of 60 times per second in the vertical direction (called the "field frequency"). Because of a half line remaining at the end of 1/60 of a second, a double interlace will automatically result, and it will take 1/30 of a second for the aperture to return to its original point. (This is known as the "frame interval," corresponding to a "frame frequency" of 30 cps.)

It is, therefore, obvious that for a picture which is not changing or moving,[1] all frequency components of the video signal will be multiples of the lowest repetition rate, which is the frame frequency of 30 cps. *The entire information is carried by means of the energy at these discrete intervals, and the remainder of the spectrum is idle and unused.* Mertz and Gray[2] were the first to recognize this important fact. They pointed out that, in general, the distribution of detail in the horizontal and vertical directions was such as to give stronger components at multiples of the line frequency. For the average still picture this may be true, but it is possible to postulate patterns which give strong components near odd multiples of half the line frequency. The exact distribution of energy in the spectrum will, therefore, depend upon the relative picture detail in the horizontal and vertical directions; nevertheless, it *will* be limited to discrete lines at harmonics of the frame frequency.

Interleaving of Spectra

Since the energy of a television signal is concentrated at finite points in the spectrum, it seems reasonable to inquire into the possibility of using one or more of the "gaps" in between in order to send further information, thus making better use of the available spectrum space. This possibility was suggested by Mertz and Gray. In particular, if we had two television systems whose scanning rates were synchronized, the spectral lines of one could conceivably be interleaved with those of the other. This was first suggested by Gray.[3] In addition, a number of other systems, both for monochrome and color television, use this method either implicitly or explicitly.[4–8]

* Decimal classification: R583.1. NTSC Technical Monograph No. 3, reprinted by permission of the National Television System Committee from "Color System Analysis," Report of NTSC Panel 12.

† General Electric Co., Syracuse, N. Y.

[1] The question of a moving or changing picture is discussed later.

[2] P. Mertz and F. Gray, "A theory of scanning and its relation to the characteristics of the transmitted signal in telephotography and television," *Bell Sys. Tech. Jour.*, vol. 13, p. 464; July, 1934.

[3] F. Gray, U. S. Patent #1769920, filed April 30, 1929, issued July 8, 1930.

[4] R. B. Dome, "Frequency-interlace color television," *Electronics*, vol. 23, p. 10; September, 1950.

[5] W. P. Boothroyd: "Dot systems of color television," *Electronics*, vol. 22, December, 1949 and vol. 23, January, 1950.

[6] RCA Laboratories Division, "A six-megacycle compatible high-definition color television system," *RCA Review*, vol. 10, p. 504; December, 1949.

[7] B. D. Loughlin, "Recent improvements in band-shared simultaneous color television," Proc. I.R.E., vol. 39, p. 1264; October, 1951.

[8] "Recent Developments in Color Synchronization in the RCA Color Television System," RCA Laboratory Report; February 8, 1950.

In order to accomplish this "interleaving" of the frequency spectrum of one signal with that of the other, one signal must be moved in frequency by an amount corresponding to some odd multiple of *one-half the frame rate*, by means of modulating one signal onto a subcarrier having a frequency of this value. If this is done, it is evident that the spectral components of the modulated signal will lie halfway between those of the unmodulated signal.

It is, furthermore, of great advantage to choose as the subcarrier frequency some multiple of one-half the frame rate which is also at or near an odd multiple of *one-half the line rate*. (Since there is an odd number of lines, an odd multiple of one-half the line rate is also an odd multiple of one-half the frame rate.) This second condition arises from the fact that any spurious pattern produced by the subcarrier will be less objectionable, due to its spatial distribution. A more detailed explanation of this effect will be given in connection with the description of the operation of the receiver.

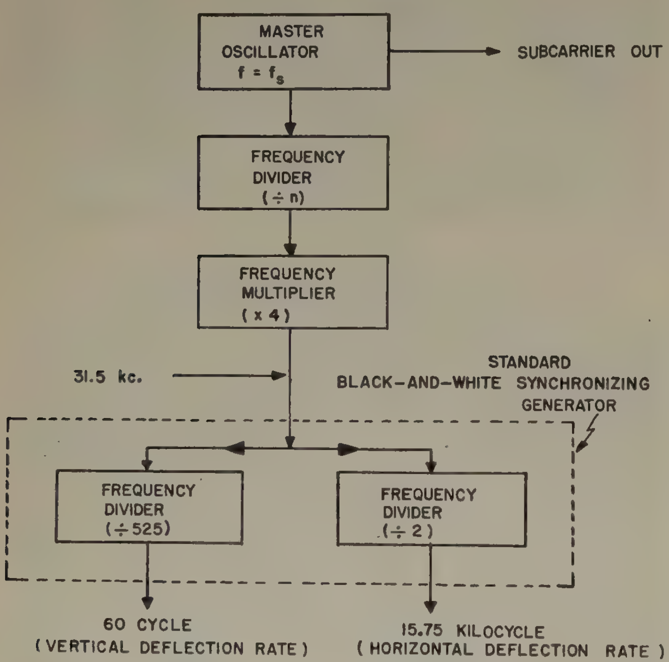

Fig. 1—Block diagram of typical synchronizing generator.

Selection and Production of Subcarrier

For practical reasons, as well as that given above, a subcarrier was chosen by the NTSC which is exactly an odd multiple of one-half the *line* rate. This point is best illustrated by considering how the subcarrier might be maintained in its proper relationship to the line and frame rates. Fig. 1 shows a block diagram of a possible system for producing the subcarrier. Its design is predicated upon two practical points. First, for large ratios, it is more desirable to divide than multiply frequency, mainly for reasons of stability. Second, because the present monochrome television system (upon which this discussion is based) uses two-to-one interlace of the lines, its frequency-divider chain starts at a frequency of twice the line rate, again to avoid the use of frequency multipliers. This being the case, the subcarrier is produced by means of an oscillator (preferably crystal) having the proper nominal frequency, namely, some odd multiple of half the line rate. This frequency is then divided down to 7.875 kc (half the line rate), and multiplied up to 31.5 kc, where it may be used to synchronize a standard synchronizing generator. Note that if we had desired to choose as a subcarrier frequency some odd multiple of one-half the frame rate, which was not also a multiple of one-half the line rate, it would have been necessary to divide all the way down to the frame rate, and the entire process of synchronizing the subcarrier and the horizontal and vertical deflection rates would have been much more complicated.

In addition, there is one more practical restriction to the choice of a subcarrier. In order to simplify the frequency division, it is desirable that the ratio, n, have relatively small factors (say, no greater than 13). (Of course, the factors will necessarily be odd!)

Hence, for all the above (purely practical) reasons, the choice of a subcarrier is narrowed considerably, although there are still sufficient possibilities.

In particular, the subcarrier frequency chosen by the NTSC is as follows: (See Appendix)

$$f_s = 3.898125 \times 10^6 \text{ cps}$$

$$= 495 \times \frac{15.75 \text{ kc}}{2}$$

$$= 11 \times 5 \times 3 \times 3 \times \frac{15.75 \text{ kc}}{2}.$$

The brightness information is then transmitted as the "main" signal, referred to as the luminance signal, while the chrominance information is modulated on this subcarrier; hence, it is "interleaved" in frequency with the brightness, since the scanning rates of the two signals are necessarily synchronized.

Separation of Signals at Receiver

In the NTSC signal, packaged as described above, there remains the problem of separating the signal components at the receiver. At first thought it would seem a rather elaborate filter, having a "comb" response, would be required at the receiver. Before taking any such drastic action, it would be well to analyze the effect of the subcarrier and its sidebands on the picture formed by the luminance signal. Consider first the case of a single frequency which lies exactly halfway between two harmonics of the frame frequency. Then, to the extent that the light-output versus voltage-input characteristic of the reproducing device is linear, the brightness along any given line will vary in a sinusoidal

manner. Since this frequency lies between two harmonics, however, it will pass through an integral number *plus one-half* cycles during a frame. This means that the sinusoidal brightness variations during corresponding lines of successive frames will be 180 degrees out of phase with each other. Hence, due to persistence of vision of the human eye, there is a tendency for the brightness variations on successive frames to cancel each other. The same effect, of course, holds for all sidebands of the subcarrier, provided that they fall in between the harmonics of the main signal. It has been called "physiological filtering" by Dome.[4] Because of nonlinearities in the reproducing devices, and the fact that the eye is not a perfect integrator, the above-described "time integration" is not completely sufficient. It should be recalled, however, that the subcarrier frequency has also been chosen to be an odd multiple of one-half the line rate. As a result, in a given field, a point on one line which is made brighter due to the presence of the subcarrier, will lie directly above a point on a succeeding line which is made darker. Therefore, a "space integration" takes place between lines when the picture is viewed at a distance sufficient to make the lines disappear.

Hence the space and time integration phenomena combine to bring the visibility of the color-carrier signal in the luminance signal, and vice versa, to a minimum. Thus, separation of two "interleaved" television signals at the receiver may be done simply by demodulating (if necessary) each signal with respect to its own carrier. Interference from the other signal will tend to cancel out automatically.

In the particular case of the NTSC color signal, this means that if a standard monochrome receiver should receive this signal, it will demodulate the luminance component signal in the usual manner, while the interfering effects due to color-carrier signal will be minute; hence, the NTSC signal (from this point of view, at least) can be said to be compatible. Again, in the case of a color receiver, the luminance component is extracted as was done in the monochrome receiver; the chrominance is recovered by means of synchronous detectors or product demodulators. (The reason for this lies in the fact that two pieces of information are sent on the subcarrier; it is not fundamental to the present discussion.) Interference between the two information channels is held to a minimum because of the interleaving of their spectral components.

Moving or Changing Subject Matter

If there is motion in the televised image, there arises the possibility of frequency components anywhere in the spectrum, since the fundamental frequency might have any possible value, depending on the amount of motion. Consequently, there will be some interference effects in this case. This may be more easily visualized by considering the case of cancellation of the interference between successive frames (time integration). Obviously, if there is an appreciable change from frame to frame, complete cancellation cannot take place. If, however, an object is in motion, interference effects in it will be less noticable due to the very fact that it *is* in motion. It should be noted that the lack of cancellation will come into play only at the edges of a moving object, and only if the speed of motion is such as to cause an appreciable change from frame to frame. Furthermore, the space integration will be affected very slightly by motion in the picture.

Conclusion

It has been shown that it is possible to overlap the spectra of the luminance and color-carrier signals in the NTSC standards, and still keep mutual interference to a tolerable minimum. This is done by modulating the chrominance signal on a subcarrier which has the proper relationship to the frame and line rates of the system.

As a result, two advantages are obtained:

(1) The standards for color television are fully compatible with those of present monochrome television.
(2) Greater bandwidth for both luminance and chrominance signals is obtained within the standard channel than would otherwise be possible.

It can, therefore, be said that the NTSC color signal can be received on either a standard monochrome receiver (in black-and-white, but with no changes in the receiver), or on a color receiver (in color). In either case, the resolution will be equivalent to that obtained with present monochrome standards, and there will be substantial freedom from interference due to the subcarrier.

Appendix

It should be noted that, in accordance with the revised NTSC standards (February, 1953), the following frequencies are now applicable:

Subcarrier frequency, f_s, = 3.579545 mc
Horizontal frequency, f_h, = 15,734.26 cps
Field frequency, f_f, = 59.94 cps

Thus,

$$f_s = \frac{455}{2} \times f_h$$

$$= \frac{13 \times 7 \times 5}{2} \times f_h$$

The reasons for these changes, as well as an explanation of the choice of these particular frequencies, are given in another paper by the author.[9]

[9] I. C. Abrahams, "Choice of chrominance subcarrier frequency in the NTSC standards," Proc. I.R.E., pp. 79, 80; this issue.

Quadrature Cross Talk in NTSC Color Television*

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Summary—**This paper discusses the quadrature cross talk in NTSC color television caused by the transmission of the chrominance information by a vestigial sideband system.**

THE PICTURE information in NTSC color television is transmitted by two simultaneous signals. One of these is the monochrome signal which is similar to that now used for present day black and white television. The other is the chrominance signal which supplies the coloring information. The chrominance information consists of two independent components, which, for the production of an optimum color picture with minimum visual degradation in the colored portions, are two color-difference signals E_Q' and E_I' (to be defined later).

These two components of chrominance E_Q' and E_I' are present as independent modulations of a color subcarrier whose frequency is 3.579545 mc.

A sine wave can carry two independent sets of information by resolving the sine wave into two components in quadrature, amplitude modulating each component with one set of information and combining the two amplitude modulated waves into a single signal. This process is used to generate the chrominance subcarrier signal in NTSC color television, and it results in a subcarrier modulated in both amplitude and phase. The instantaneous amplitude of the chrominance subcarrier is approximately proportional to the product of luminance times purity for a picture element, while the phase of the subcarrier is found to be in one to one relation with the dominant wavelength of the picture element. Each modulation component can then be recovered by heterodyning the complete modulated wave with a sine wave having the same frequency and phase as the carrier component having the desired modulation. This process is called synchronous detection or product-demodulation and must not be confused with other forms of detection which recover the modulation envelope.

The two modulations remain independent only when the modulated waves each consist of like upper and lower sidebands. When the sidebands are not equal, the modulations, E_Q' and E_I' in this case, cross talk on each other and the color is contaminated. This paper describes how the cross talk comes about, derives the wave forms of cross talk, and shows how its effect may be minimized.

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† Hazeltine Corp., Little Neck, L. I., N. Y.

Generation of the Color Picture Signal

A scheme for generating the color picture signal is shown in Fig. 1. Color synchronizing information in the form of a short burst of the color subcarrier at a reference phase of sin $(\omega t+180°)$ is transmitted after each horizontal synchronizing pulse. This signal is used to maintain a local color reference subcarrier in the receiver at the proper frequency and phase for the detection process. For simplicity, the circuits for generating the color burst are not shown in Fig. 1.

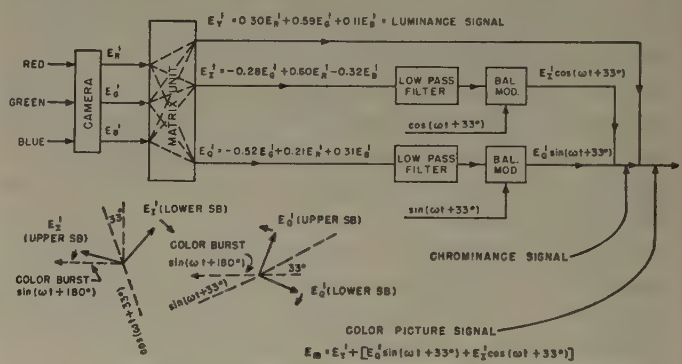

Fig. 1—Block diagram of transmitter.

The camera voltages E_G', E_R', and E_B' are mixed to form the monochrome and color-difference signals.

The color-difference signals are

$$E_I' = -0.27(E_B' - E_Y') + 0.74(E_R' - E_Y') \tag{1}$$

$$= -0.28E_G' + 0.60E_R' - 0.32E_B' \tag{1a}$$

and

$$E_Q' = 0.41(E_B' - E_Y') + 0.48(E_R' - E_Y') \tag{2}$$

$$= -0.52E_G' + 0.21E_R' + 0.31E_B' \tag{2a}$$

and the monochrome signal is

$$E_Y' = 0.30E_R' + 0.59E_G' + 0.11E_B'. \tag{3}$$

These three signals are formed in a matrix as shown. E_I' and E_Q' are passed through low-pass filters to limit the bandwidth of these signals to the values recommended by the NTSC. E_I' is then used to modulate a carrier cos $(\omega t+33°)$ while E_Q' modulates a carrier sin $(\omega t+33°)$. Balanced modulators are used in each case so that only the sidebands resulting from the modulation processes are transmitted. The outputs of the two modulators are first combined to form a single color subcarrier, or chrominance, signal and then combined with the luminance signal to form the color picture signal E_M whose equation is:

$$E_M = E_Y' + [E_I' \cos(\omega t + 33°) + E_Q' \sin(\omega t + 33°)]. \tag{4}$$

The relative phase of the two sets of chrominance sidebands is shown in Fig. 1. The color picture signal (see Fig. 2) is then applied to the radio frequency transmitter. The frequency band here is generally limited so that vestigial sideband transmission of the color subcarrier results.

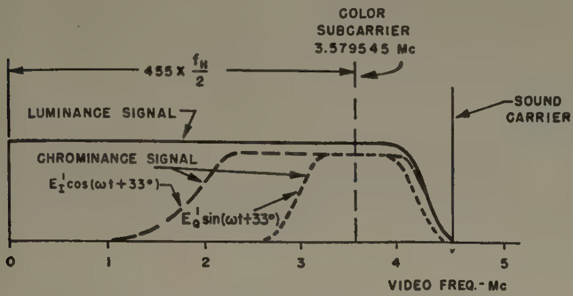

Fig. 2—Color picture signal pass-band.

Color Receiver

Fig. 3(a) shows a block diagram of a typical receiver. The color picture signal, monochrome plus attenuated subcarrier, is applied to the three grids of the picture tube. This signal drives the three grids and produces a monochrome picture.

The signal is also applied to the demodulators through a separate path. A band-pass filter is inserted into this circuit to attenuate the low-frequency monochrome components and sound carrier. The synchronous detection will first be described as if the signal had double sidebands, then the correction required for vestigial sidebands will be described.

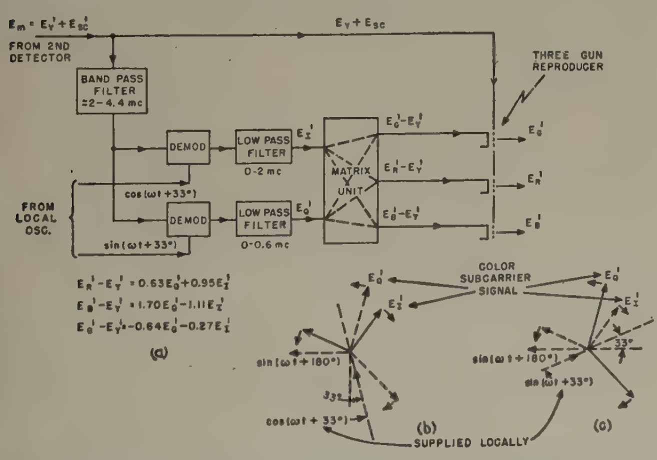

Fig. 3—Block diagram of receiver with vector diagrams of demodulation.

The complete color subcarrier signal is applied to each demodulator and consists of two sets of sidebands as shown in Figs. 3(b) and 3(c). A synchronous local subcarrier is generated within the receiver. One component having the phase cos $(\omega t+33°)$ is applied to the I channel color-difference demodulator as shown in Figs. 3(a) and 3(b). Another component sin $(\omega t+33°)$ is applied to the Q channel color-difference demodulator as shown in Figs. 3(a) and 3(c). Recovery of the color-difference signals will first be described as though both sidebands of the chrominance subcarrier were transmitted. The entire color subcarrier signal and a chrominance-carrier reference of phase sin $(\omega t+33°)$ are supplied to the Q channel demodulator. The two sidebands E_Q' of the Q channel chrominance component are seen to have components along the reinserted sin $(\omega t+33°)$ carrier which are in phase and add to produce the desired E_Q' color-difference video signal [see Fig. 3(c)]. The two components E_I' are seen to have components along the reinserted sin $(\omega t+33°)$ carrier which are in opposition. They therefore cancel and produce no output. In a similar manner, it can be seen that from the demodulator for which the chrominance-carrier reference is cos $(\omega t+33°)$, the sidebands E_I' produce the desired E_I' color-difference output signal while the components E_Q' produce no output. Thus, the E_I' and E_Q' color-difference signals are recovered at the receiver, and by suitable combinations with the monochrome signal are used to drive the picture reproducer.

The information which is utilized to re-establish the reference frequency and phase at the receiver is transmitted by a few cycles of the reference signal having the phase sin $(\omega t+180°)$, called the Color Burst, on the horizontal blanking pulse following the line synchronizing pulse. Its frequency is that of the chrominance subcarrier (3.579545 mc).

Color Cross Talk Due to Single Sideband Operation

It is desirable to use a high frequency (3.579545 mc) for the color subcarrier to reduce its visibility in monochrome receivers. This limits the frequency range over which upper sideband may be used for the chrominance components since the total video range is limited in practice to less than 4.5 mc. However, the lower sidebands may extend for a considerable range, one or two mc below the chrominance subcarrier. These unequal sidebands result in cross talk of one component of the chrominance subcarrier to the other one.

Single sideband modulation results in the division of the power equally between amplitude and phase modulation for these modulation frequencies. Stated in another way, it results in two sets of equal sidebands, one set being in phase and the other set in quadrature with the carrier. This is shown in Fig. 4.

Figs. 4(a1) and 4(a2) show, on a frequency and time diagram respectively, the relation between a chrominance subcarrier $E_0=\cos(\omega t+33°)$, which may be suppressed, and a lower sideband $E_L \cos[(\omega-\omega_L)t+33°]$. The phase of E_0 is arbitrarily made the reference phase which, for convenience in this discussion, is also made the phase of the I color-difference channel.

Figs. 4(b1) and 4(b2) represent the same signal except that an upper sideband

$$+E_U = \frac{E_L}{2} \cos[(\omega+\omega_L)t+33°],$$

having half the amplitude of the lower sideband, has been added symmetrically about the reference phase; however, another signal

$$-E_U = \frac{-E_L}{2}\cos\left[(\omega+\omega_L)t+33°\right]$$

which is equal but opposite in phase to $+E_U$ has also been added so as to leave the signal shown in Fig. 4(b) identical to that of Fig. 4(a).

The sidebands shown in Fig. 4(b) can now be separated into two sets of equal sidebands. One of these sets (E_p and E_p') is shown in Figs. 4(c1) and 4(c2) and is symmetrically disposed about the reference phase ($\cos\omega t+33°$). These sidebands represent pure amplitude modulation of $\cos\omega t+33°$ (the I channel subcarrier). The second set (E_q and E_q') is symmetrically disposed about a second carrier which is in quadrature with the reference carrier. E_q and E_q' therefore result in amplitude modulation of $\sin\omega t+33°$ (that is, of a subcarrier having the reference phase of the Q channel).

It is obvious that the sum of the signals of Fig. 4(d) and 4(c) equals the signal of Fig. 4(b) and therefore of Fig. 4(a).

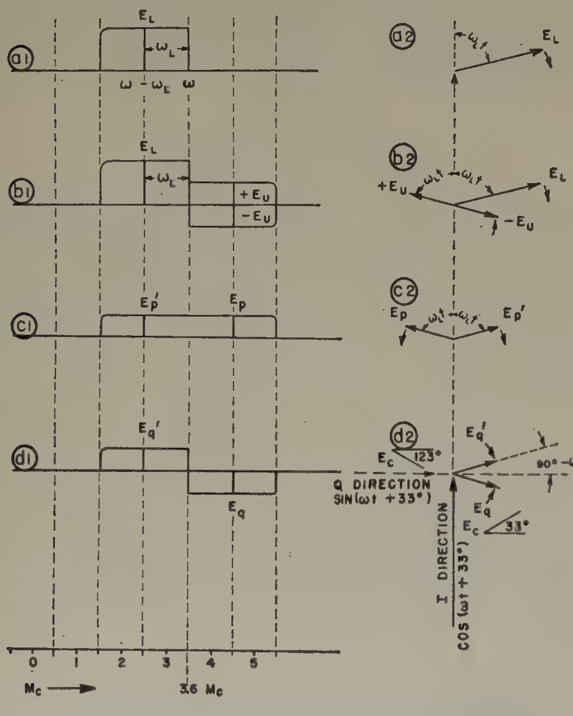

Fig. 4—Analysis of single sideband transmission.

It is important to note that *the phase of the envelope component produced by E_q and E_q' along sin $(\omega t+33°)$ is in quadrature with the phase of the envelope component produced by E_p and E_p' along* $\cos(\omega t+33°)$ and that the two sets of quadrature sidebands are equal.

Thus an I channel signal, amplitude modulating a carrier by means of double sidebands, will, on losing one sideband, have part of its energy transferred to a component, in quadrature with the carrier, which will appear as a spurious signal in the Q channel. This spurious signal will have a different wave form than the I channel signal which caused it because each frequency component of the spurious signal in the Q channel is shifted in phase by 90° over the corresponding I channel component.

Wave Form Due to Quadrature Cross Talk

It is interesting to know what wave forms may be expected when the receiver circuits selectively attenuate a double sideband chrominance subcarrier.

Assume for simplicity that the transmitted chrominance signal consists of a square-wave I channel signal having a frequency equal to the fifth harmonic of line frequency, i.e. ($5\times 15.734=78.67$ kc) (in N T S C color television the horizontal scanning frequency is $2/455\times 3.579545$ mc$=15.734+$kc. This frequency is substantially the same as the nominal 15.75 kc normally used in black and white television), and an amplitude E, as shown in Fig. 5(a2). This signal consists only of odd harmonics, whose amplitudes are inversely proportional to their order. By choosing $t=0$ to coincide with its rising edge, the square wave is found to be described by

$$E(t) = \frac{4}{\pi}\sum_{n=1}^{n=h}\frac{E}{n}\sin n\omega_1 t$$

where

$\omega_1 = 2\pi\times 78{,}671$ rad/sec

$n=1, 3, 5, 7, \cdots h.$

The suppressed-carrier amplitude-modulation of a chrominance subcarrier, $\cos(\omega t+33°)$, by this signal results in the symmetrical sideband distribution shown in Fig. 5(a1), where the number beneath each sideband corresponds to a harmonic of 78.67 kc. At any one instant t_1, each pair of sidebands is phased symmetrically about the carrier, $\cos(\omega t+33°)$, as shown in Figs. 4(c1) and 4(c2).

Let us assume that this signal is passed through a filter having the characteristic shown in Fig. 5(b1), which is assumed to have constant delay for all frequencies. This filter passes the sets of sidebands corresponding to the fundamental, third, and fifth harmonic of the modulation with unity transmission. These modulation components are shown in their proper relative phase and amplitude in Fig. 5(b2). They are labelled (1), (3), and (5) respectively. The sidebands corresponding to these components add to produce an envelope whose wave form is shown as the heavy line in Fig. 5(b2). Since the modulation was assumed to be produced by an I channel signal, this is the wave form of the video output of an I channel demodulator on which a signal having this envelope is impressed.

On the other hand, the filter whose characteristic is shown in Fig. 5(c1) results in shifting each modulation component shown in Fig. 5(b2) by 90°, as shown in Fig. 4(d2). The shifted components which are shown in Fig. 5(c2) add to produce the wave form shown in Fig. 5(c3) which is the envelope of a carrier in quadrature with the one having the envelope shown in Fig. 5(b2), as can be seen by referring again to Fig. 4. Fig. 5(c3) is therefore the wave form that would appear at the output of a Q channel demodulator.

Since the filter characteristics of Figs. 5(b1) and 5(c1) add to produce the single sideband characteristic shown in Fig. 5(d1), the heavy line in Fig. 5(b2) shows the wave form of the envelope of the "in-phase" component and Fig. 5(c3) shows the wave form of the envelope of the "quadrature cross talk" produced by a square-wave modulated I channel color-difference signal passing through the single-sideband filter of Fig. 5(d1).

A similar treatment will yield the envelope wave forms of the "in-phase" and "quadrature" components of a filter whose characteristic is shown in Fig. 6(b1). This filter can be analyzed into two components whose characteristics are shown in Figs. 6(c1) and 6(d1) respectively. The filter of Fig. 6(c1) has mirror-symmetry about the chrominance subcarrier and passes equally well all sidebands up to and including those corresponding to the eleventh harmonic of the modulation shown in Fig. 6(a2). These sidebands result in an "in-phase" component whose envelope is shown in Fig. 6(c2). This wave form was plotted by performing the following operation.

$$\frac{4}{\pi}\sum_{n=1}^{n=11}\frac{E}{n}\sin n\omega_1 t$$

where

$n=1, 3, 5, \cdots$

$\omega_1=2\pi\times 78{,}671$ rad/sec.

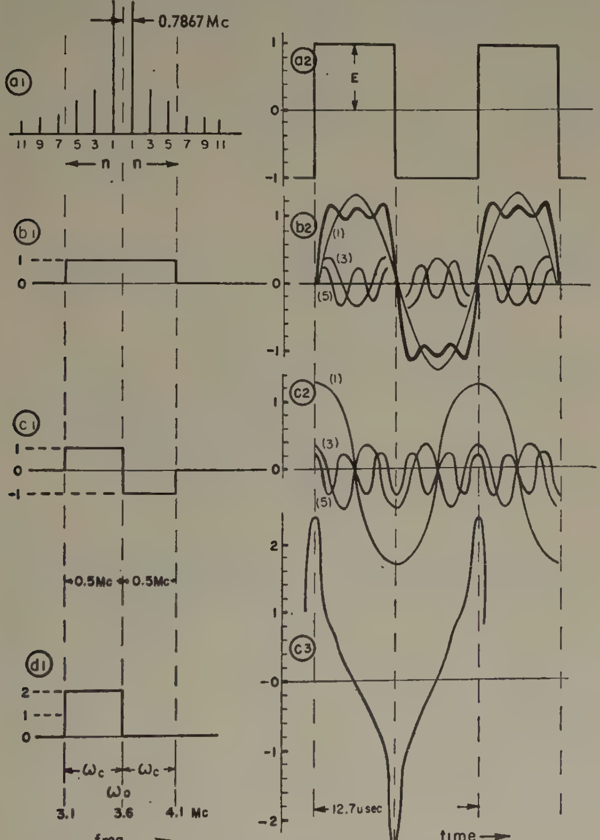

Fig. 5—In-phase and quadrature components with single sideband transmission.

The signal shown in Fig. 6(a1) is transformed to that of Fig. 6(e1), which contains only sidebands corresponding to the seventh, ninth, and eleventh harmonics after passing through the filter shown in Fig. 6(d1). The skew-symmetry of the sidebands results in shifting each component of the modulation by 90° as shown in Fig. 4. The sum of these components (which is expressed by

$$\frac{4}{\pi}\sum_{n=7}^{n=11}\frac{E}{n}\cos n\omega_1 t$$

where

$n = 7, 9, 11$)

results in a "quadrature" component whose envelope is shown in Fig. 6(e2).

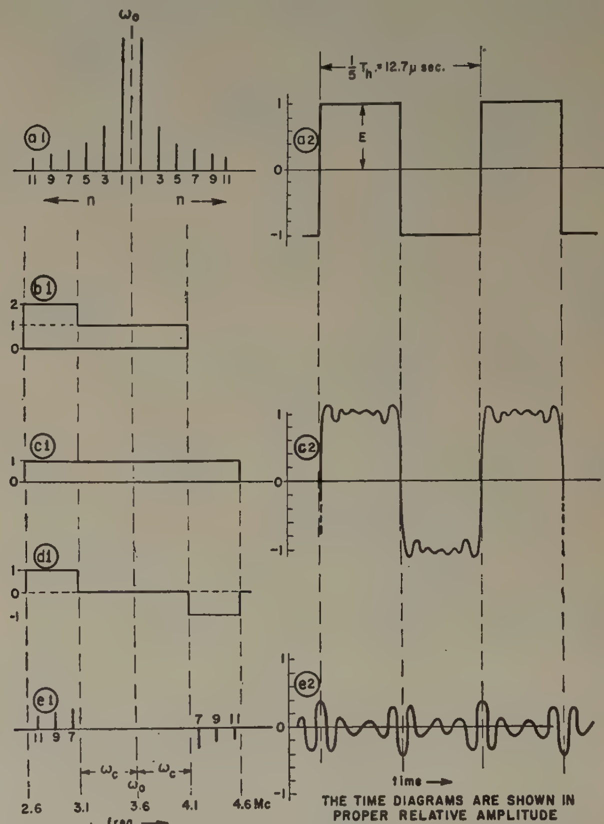

Fig. 6—In-phase and quadrature components with vestigial sideband transmission. Carrier located in a region of the pass-band where the transmission is uniform with frequency.

The filter with a linear sloping characteristic having the carrier frequency at a point whose transmission is −6 db from maximum presents interesting sidelights. Such a filter is shown in Fig. 7(a1). Its characteristic can be separated into "mirror-symmetrical" and "skew-symmetrical" components. The "mirror-symmetrical" component is shown in Fig. 7(b1) and is seen to be the same as the filter characteristic shown in Fig. 6(c1) so that the "in-phase" component envelope is as shown in Fig. 6(c2) which is repeated in Fig. 7(b2). The "skew-symmetrical" component which gives rise to the quadrature component is shown in Fig. 7(c1). It can also be resolved into two components. One of these, shown in Fig. 7(d1), has already been discussed and found to give

the envelope wave form shown in Fig. 7(d2). The second "skew-symmetrical" component is shown in Fig. 7(e1). If we compare the envelope produced by a pair of sidebands passing through the filter of Fig. 7(e1), with the envelope produced by an identical pair of sidebands passing through the reference filter of Fig. 7(f1), we find that:

1) Each component is shifted by 90°.
2) Because of the sloping nature of the skew-symmetrical characteristic, the amplitude of each component of the skew-symmetrical signal is equal to the amplitude of the corresponding mirror-symmetrical signal through the reference filter multiplied by the factor $n(\omega_1/\omega_c)$.

Since, as shown in Figs. 7(e1) and 7(f1), both filters are limited to a bandwidth which passes only those sidebands which correspond to the fundamental, third, and fifth harmonic:

The envelope of "in-phase" component
[shown in Fig. 7(f2)]

$$= \sum_{n=1}^{n=5} \frac{4}{\pi} \frac{E}{n} \sin n\omega_1 t.$$

The envelope of "quadrature" component
[shown in Fig. 7(e2)]

$$= \sum_{n=1}^{n=5} \left(n \frac{\omega_1}{\omega_c}\right) \frac{4}{\pi} \frac{E}{n} \cos n\omega_1 t.$$

The envelope of "quadrature" component
[shown in Fig. 7(e2)]

$$= \frac{1}{\omega_c} \frac{d}{dt} \sum_{n=1}^{n=5} \frac{4}{\pi} \frac{E}{n} \sin n\omega_1 t.$$

The envelope of "quadrature" component
[shown in Fig. 7(e2)]

$$= \frac{1}{\omega_c} \frac{d}{dt} \text{ (envelope of ``in-phase'' component).}$$

In other words, the sloping characteristic of Fig. 7(e1) results in a "quadrature" component whose envelope wave form is the time derivative, multiplied by $1/\omega_c$, of the envelope of the "in-phase" signal shown in Fig. 7(f2). The linear drop-off should be as gradual as possible to minimize the amplitude of the derivative as shown by the factor $1/\omega_c$.

The wave form of the envelope of the quadrature component, produced when the signal shown in Fig. 6(a2) passes through a filter having the characteristic of Fig. 7(a1), is shown in Fig. 7(c2) which is equal to the sum of the wave forms shown in Figs. 7(d2) and 7(e2).

It is believed that this method of analysis which makes use of periodic signals, instead of the more general single transient, is typical enough of the television case. The effects of the circuits on a limited number of harmonics can be easily determined and a physical understanding of the process is readily obtained. While the pass-bands were assumed to be uniform in amplitude and time delay for all frequencies of interest, the method is not limited to these cases and each component making up the envelope may be changed in amplitude or shifted in phase as the actual case may require.

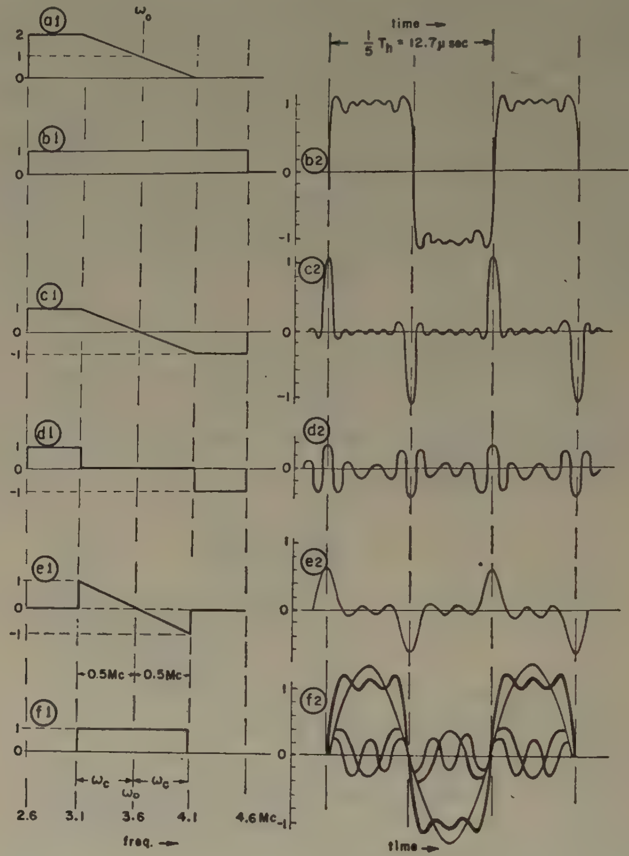

Fig. 7—In-phase and quadrature components with vestigial sideband transmission. Carrier located in a region of the pass-band where the transmission is varying linearly with frequency.

It should be noted that the wave form of the quadrature cross talk produced by vestigial or single sideband transmission as shown in Figs. 5, 6, and 7 has mirror symmetry about the change in signal which produced it. Thus, for a step of modulation, the quadrature envelope has a pulse shape symmetrically located about the step. This symmetry is characteristic of distorting the signal in amplitude only. Any departure from mirror symmetry noted in a quadrature cross-talk signal is indicative of phase distortion in the channel. These effects may be noted in NTSC television by producing a step of modulation, as by a square wave in one chrominance channel, say the I channel, while the Q channel is disabled at the transmitter and observing the output in the Q channel in the receiver.

Reduction of Color Cross Talk in NTSC Color Television

In NTSC color television, the deleterious effects of color cross talk with vestigial sideband transmission of the chrominance subcarrier just discussed are avoided by the judicious choice of bandwidths of the two modulations. The bandwidth, prior to modulation of the

chrominance subcarrier at the transmitter, of one of the chrominance signals is limited to a value which assures that both the upper and lower sidebands of this signal can be maintained substantially alike in the transmitter and receiver. This is the signal in the Q channel, and its bandwidth, as a video signal at the transmitter, is limited to a maximum value of 600 kc at 6-db attenuation. The other component of chrominance is designated as the I signal and prior to modulation at the transmitter it is handled in a channel whose bandwidth is not less than 1.3 mc at 2-db attenuation and not greater than 3.6 mc at 20-db attenuation.

Experiments have shown that if one component of chrominance is to be transmitted with reduced bandwidth, there is an optimum chrominance axis along which the signal should be narrow band. Fig. 8 shows a chromaticity diagram on which the gamut of colors which may be reproduced in NTSC television is shown.

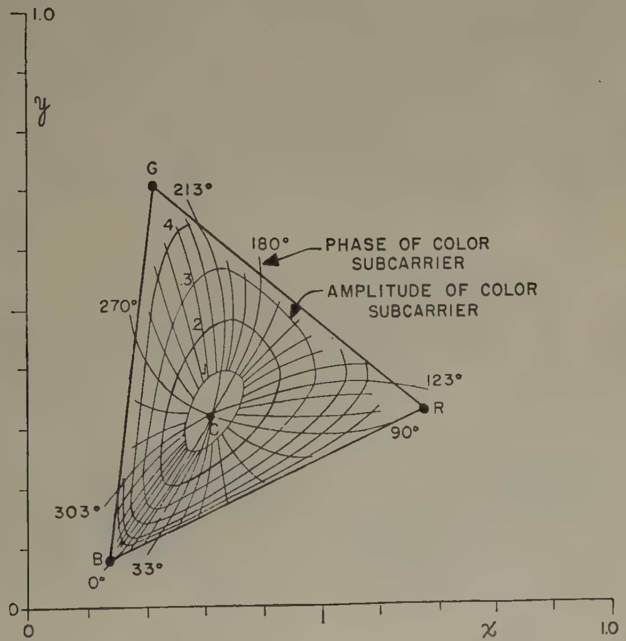

Fig. 8—Chromaticity diagram showing color subcarrier as a function of reproduced chromaticity.

Superposed over the color gamut is a grid giving the co-ordinates in amplitude and phase of the chrominance vector as a function of the chromaticity of the reproduced color. The grid is nonlinear because of the effect of nonlinear transfer characteristic of the color reproducer at the receiver. (This figure was taken from "Colorimetry in Color Television," by F. J. Bingley, Panel 12, Monograph No. 8 NTSC.) Specifically these experiments indicated that the subjective effect of the degradation due to narrow-band transmission is least objectionable if the chrominance axis chosen for the narrow-band channel is along the 33°–213° axis of Fig. 8. The wide band chrominance signal is in quadrature to this along the 123°–303° axis. The compositions of the signals E_Q' along the 33°–213° axis and E_I' along the 123°–303° axis are those stated in (1a) and (2a).

Since the information in the Q channel has been limited at the transmitter to that contained in a band about 600 kc wide, the Q channel in the receiver following the synchronous detector can also be restricted to about the same bandwidth without any degradation of the desired signal in this channel. Thus, as shown in Fig. 9(a), the color receiver may be constructed so that the transmission measured from the antenna terminals to the input of the synchronous detectors in the color decoder is substantially flat over the video frequency range of about 2 to about 4 mc. Fig. 9(b) shows on the same frequency scale the maximum sideband content of the Q signal. This signal is therefore transmitted to the synchronous detector with like upper and lower sidebands. As shown previously, this means that none of the Q-signal information will be found in the I channel.

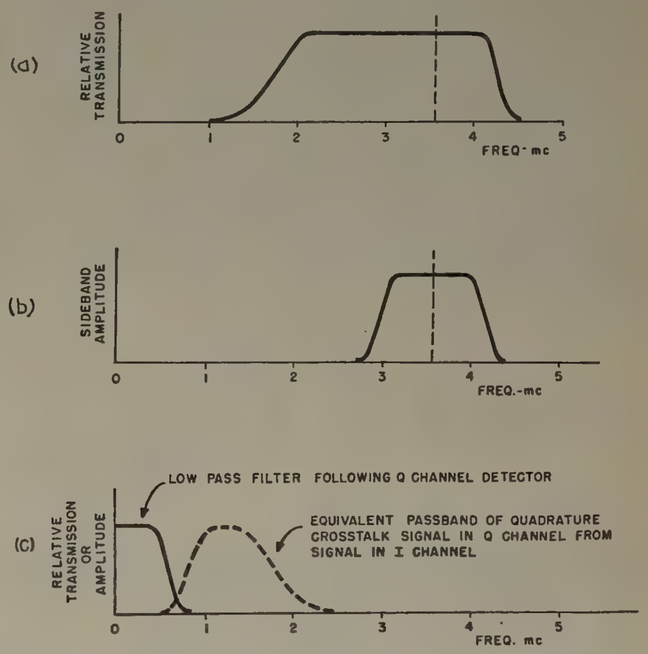

Fig. 9—(a) Transmission from antenna to demodulator inputs in color receiver. (b) Maximum sideband content of color subcarrier modulated by Q signal. (c) Q channel in receiver following demodulator.

The I-channel signal is wide-band, and the modulated subcarrier may have a sideband content similar to the transmission curve of Fig. 9(a). In this case there is considerable asymmetry between upper and lower sidebands with the result that a quadrature cross-talk signal will be produced in the Q channel. This cross-talk signal is seen from the discussion of Fig. 6 to correspond to video frequencies after detection from about 0.6 to 2 mc, and it is contained in a pass-band as shown in dashed lines in Fig. 9(c). However, by the use of a low-pass filter with at cutoff at 0.6 mc following the Q-channel synchronous detector as shown in Fig. 9(c), this undesired quadrature cross talk may be attenuated to any desired degree. This signal composition and receiver design permits us to obtain the I and Q signals at the receiver each free of cross talk due to vestigial sideband transmission of the color subcarrier signal.

The ability to obtain the detected Q and I signals at the receiver each with negligible cross talk from the other is seen to be possible if there are no cross-talk signals having video frequencies after detection less than 0.6 mc. The discussion of Figs. 6 and 7 indicate that this may be accomplished by having a chrominance subcarrier pass-band which is flat over a frequency range of about ± 0.6 mc from the subcarrier. Note particularly that the sloping type of pass-band of Fig. 7 will result in cross talk in both the Q and I detected signals in the video frequency range of 0 to 0.6 mc. *Note:* A previous version of NTSC color television used a chrominance subcarrier at 3.89+ mc and equal bandwidth of the two chrominance components. This resulted in considerable asymmetry of the sidebands of the chrominance subcarrier signal. The quadrature cross talk was minimized in this case by the use of "Color Phase Alternation" which was practiced by reversing the phase of one of the color subcarrier components on successive fields. A corresponding reversal was made in the receiver to enable the desired polarity of signal to be obtained at all times. By this means, the polarity of the cross talk from each chrominance channel into the other was reversed on successive fields so that the cross talk tended to integrate out in the picture since its polarity was opposite on successive lines in the complete picture. Some edge flicker due to incomplete cancellation (caused largely by failure to achieve true constant luminance operation) and flicker in large areas under some conditions of extreme misphasing were experienced with this system. However, the change in color subcarrier to 3.57+ mc, in conjunction with other changes in the signal make-up and in apparatus design, has so alleviated the quadrature cross talk that color phase alternation appears to be no longer necessary.

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Narrow-Band Transmission of the NTSC Color Signal*

JOSEPH G. REDDECK†

***Summary*—A description is given of a method which makes possible the transmission of a subcarrier-type color television signal over narrow-band coaxial cables. Luminance detail is limited to approximately 2 mc, while color detail is limited to 0.3 mc.**

THE NTSC STANDARDS provide for a highly-efficient transmission of useful information in the allotted spectrum. This efficiency is achieved by band sharing of luminance and chrominance components in the band normally required for monochrome pictures. Band sharing is accomplished by adding to the luminance information a subcarrier which is modulated by chrominance information. The subcarrier frequency is chosen to be an odd multiple of half the line frequency (and consequently an odd multiple of half the frame frequency) for "frequency interleaving" of luminance and chrominance information. The complete video spectrum of the NTSC field-test signal (Fig. 1); f_h is the horizontal scanning frequency of nominally 15,750 cycles.

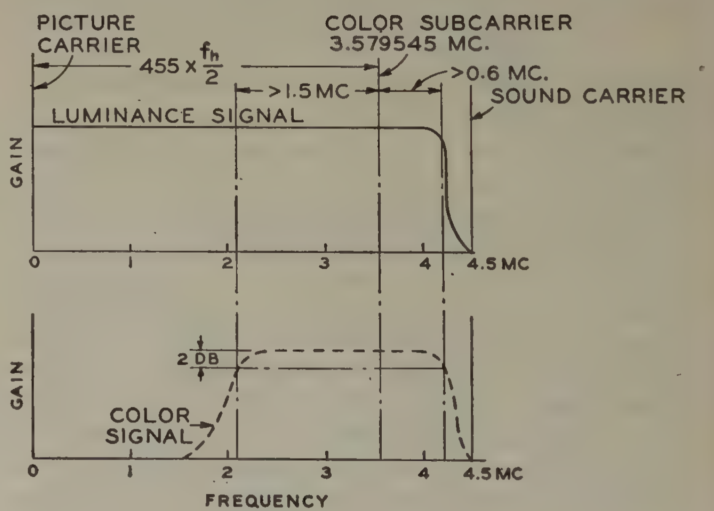

Fig. 1

The problem of sending the NTSC color signal over a narrow-band transmission system arises in networking of television programs over existing coaxial cable circuits. When a normal monochrome signal is transmitted over such a system, the resulting reduction of detail is accepted. When the NTSC color signal is sent over a system having a bandwidth much less than 4.3 mc, the chrominance information is lost entirely unless suitable terminal equipment is inserted at the terminals of the coaxial cable. The bandwidth of the type L-1 coaxial cable limits the total spectrum of the signal to approximately 2.7 mc.

* Decimal classification: R583. NTSC Technical Monograph No. 5A, reprinted by permission of the National Television System Committee from "Color System Analysis," Report of NTSC Panel 12.
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The retention of much of the chrominance information in the NTSC color signal is accomplished by means of terminal equipment described below. The transmitting terminal equipment divides the composite color signal into two bands of frequencies as indicated in Fig. 2.

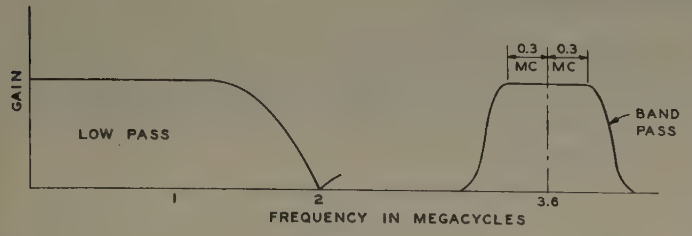

Fig. 2

The first band contains frequency components of the signal which extend from 0 to 2 mc. The second band contains components whose frequencies extend 0.3 mc on each side of the subcarrier frequency f_s, 3.579545 mc.

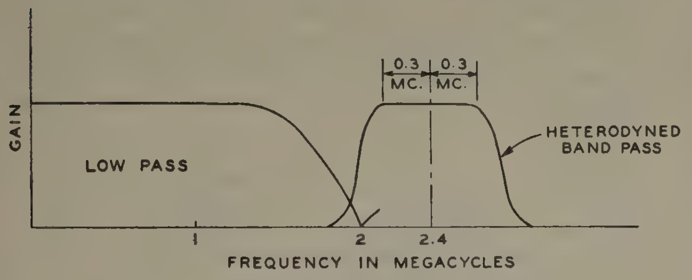

Fig. 3

This second band is moved down in frequency by heterodyning so that it is adjacent to the 0- to 2-mc band. The new spectrum of the signal is thus limited to 2.7 mc, as shown in Fig. 3. This signal is sent over the coaxial cable to the receiving terminal equipment. This equipment separates the two bands of Fig. 3 and moves the upper band back to its original position by heterodyning.

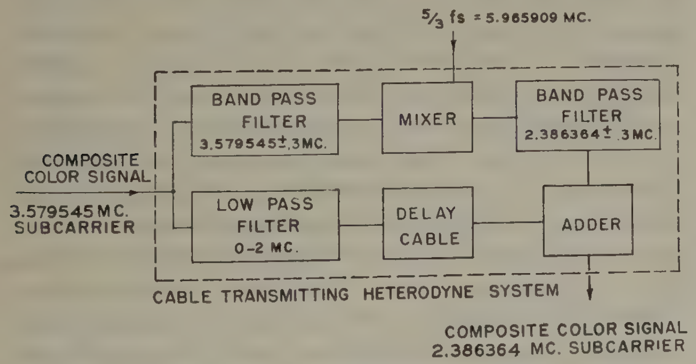

Fig. 4

Fig. 4 shows a block diagram of the transmitter terminal equipment which alters the NTSC color signal for narrow-band transmission. First, a linear-phase-shift low-pass filter selects the luminance components extending out to 2 mc. An *m*-derived band-pass filter selects the components which extend 0.3 mc on each side of the subcarrier frequency f_s, 3.579545 mc. This band is then lowered by heterodyning in a mixer with a sine wave voltage whose frequency is 5/3 times the color subcarrier frequency, f_s, or 5.965909 mc. A second *m*-derived band-pass filter follows the mixer. This filter selects only the difference frequency components, which extend 0.3 mc on each side of $2/3\,f_s$, or 2.386364 mc. This band around 2.386364 mc is then added to the low-pass band to give a spectrum as shown in Fig. 3. Note that now all components which were originally near 3.579545 mc are now near 2.386364 mc. In effect, the subcarrier has been lowered. The synchronizing burst is now a burst of 2.386364 mc. The spectrum of Fig. 3 can now be transmitted over a system limited to about 2.7 mc.

Fig. 5 shows the block diagram of the receiver terminal equipment which must translate the 2.386364-mc subcarrier back to 3.579545 mc. Another linear-phase-shift low-pass filter selects the luminance components extending out to 2 mc. An *m*-derived band-pass filter selects the components extending 0.3 mc on each side of 2.386364 mc. This band is then heterodyned in a mixer with a signal whose frequency is again $5/3\,f_s$, as in the transmitting terminal. Another *m*-derived band-pass filter following the mixer selects only the difference frequency components, which extend 0.3 mc on each side of f_s. Thus the color subcarrier is moved back to its original value. The band around 3.579545 mc is added to the low-pass band. The spectrum of Fig. 2 is recovered and the signal is ready for transmission as a NTSC color signal of reduced detail.

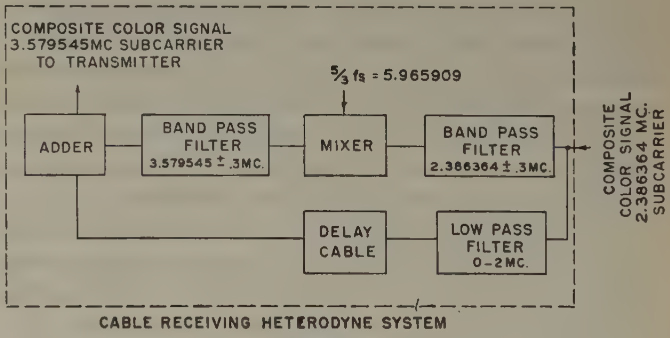

Fig. 5

It should be pointed out that the heterodyning signals at both the transmitting and receiving ends of the terminals must be locked to the original subcarrier, f_s, in order to maintain the 455/2 ratio between the subcarrier and line frequency. This is accomplished by automatic-frequency-control circuits in both the transmitter and receiver-terminal equipment. An oscillator in each is locked to the color synchronizing burst of its input signal. Thus the heterodyning signals and the lowered subcarrier are locked to the original subcarrier f_s. This results in the final subcarrier being identical in frequency to the original subcarrier.

It should also be pointed out that the band-pass filters at both terminals have to be carefully designed to eliminate any undesired components which are introduced by the mixers.

System Delay Characteristics in NTSC Color Television*

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Summary—**The NTSC Revised Signal Specifications include specification of signal component time coincidence and of envelope delay in the transmitted signal which compensate for certain receiver characteristics. The origin of delay errors is briefly discussed along with the means and effects of delay correction.**

Introduction

THE FCC STANDARDS of 1941[1] for monochrome television transmission specify a transmitter spectrum as shown in Fig. 1a with an implied associated receiver response as shown in Fig. 1b. Ideally, the receiver response, determined primarily by the RF and IF stages, is essentially flat to approximately 4 mc with a reduction of response to approximately -35 db at the frequency of the associated sound carrier at 4.5 mc relative to the picture carrier. Close similarity as to receiver amplitude response between different manufacfacturers implies through application of the minimum phase shift law[2] corresponding similarity of phase characteristics of different receivers. Kell and Fredendall[3] have determined that even for receivers of rather different amplitude responses the phase characteristics at the upper end of the video passband were sufficiently similar that compensation at the transmitter was practical. Correction of phase errors leads to improved system performance through an improved over-all transient response. Considerations of economy in receiver manufacture make it advisable to install such phase correction at the transmitter, even though optimum compensation for all receivers will not be achieved.

A further source of phase error arises from the transmission of television signals through a vestigial sideband system. Both the vestigial sideband filter at the transmitter and the lower sideband attenuation characteristics of the receiver contribute to this phase error; the receiver phase errors are subject to considerable variation between receivers of different manufacture and with receiver tuning. Since the transmitter characteristics are closely specified, it is possible to correct phase errors from this source, although the exact networks required will depend on the nature of the vestigial sideband filter used. Phase correction has sufficiently beneficial results to warrant a proposed standard of transmitter phase characteristics by the RTMA for monochrome television.[4]

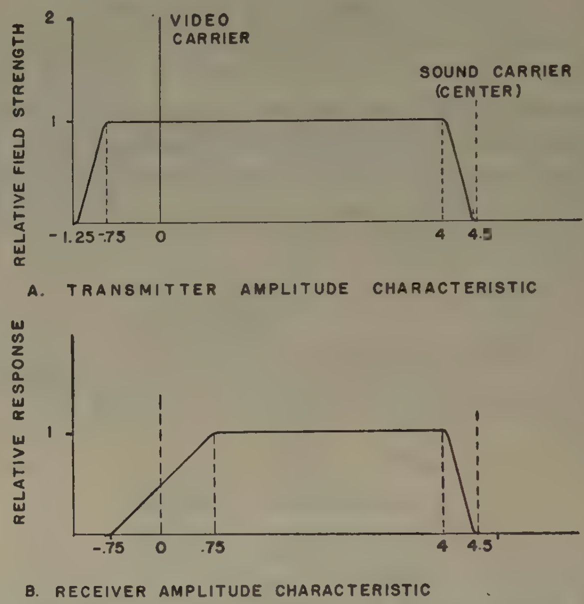

Fig. 1—Television system response.

Origin of Delay Distortion

If a transmission system or network with uniform amplitude response has a phase shift-versus-frequency characteristic which is not constant, then the slope $d\theta/d\omega$ of this plot at a selected frequency ω_0 may be physically interpreted[5] as the delay time of a small group $\Delta\omega$ of frequencies centered about ω_0 in passing through the network. This small group of frequencies will appear at the output as a cosine wave at frequency ω_0 with an envelope of the form $\sin \mu/\mu$ of width $4\pi/\Delta\omega$. The output of the system for an arbitrary input spectrum may be secured by summing all these impulses over the frequency range of interest, noting that the delay of the envelope of each group is given by the slope of the phase-frequency plot at the center of the group.

For a minimum-phase shift network (i.e., no all-pass sections or lattice sections) as represented by the circuits of a television receiver or by the vestigial sideband filter of a transmitter, the amplitude response uniquely determines the phase characteristic.[2] Since the ampli-

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[1] FCC Standards of Good Engineering Practice Concerning Television Broadcast Stations; April 30, 1941. See also: D. G. Fink, "Television Standards and Practice," NTSC, McGraw-Hill, New York, N. Y.; 1943.

[2] H. W. Bode, "Network Analysis and Feedback Amplifier Design," Van Nostrand, New York, N. Y., pp. 242 ff., 305 ff.; 1945.

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[5] E. A. Guillemin, "Communication Networks," vol. II; John W. Wiley, New York, N. Y., pp. 490 ff.; 1935.

tude characteristic of the transmitter is closely specified and that of the receiver dictated by performance requirements, the phase shift characteristics of a television system are quite closely determined. In the absence of any corrective action, the envelope delay of the television system over the range of frequencies of interest is in sufficient error to cause noticeable picture degradation. Three sources of phase distortion and associated envelope delay distortion may be enumerated:

A. Receiver High-Frequency Cutoff:

The rapid increase of attenuation in the receiver between 4 mc and 4.5 mc leads to a phase shift which is not proportional to frequency. The phase errors of the receiver become objectionable beyond a frequency of 2.5 mc. Delay distortion resulting from this phase characteristic leads to strong overshoots following steep edges in the video wave form, with visible striations to the right of edges of objects in the televised picture. Correction of this delay error distributes the overshoot symmetrically about picture transitions, reducing the magnitude of the overshoot to about one half.

B. Vestigial Sideband Transmission:

The attenuation of the lower sideband of the television signal by the transmitter sideband filter and by the receiver low-frequency cutoff characteristic results in an envelope delay which increases with decreasing frequency below 3 mc (referred to the video signal). This delay distortion results in a leading undershoot and a following slow approach to final value at steep edges in the video wave form, with an associated smearing of vertical edges in the televised picture. Correction of this delay error removes both the leading undershoot and smear distortion in the picture.

1. *Receiver Sideband Cutoff:* The lower sideband cutoff characteristic of the receiver, which locates the video carrier at a point of 50 per cent response, contributes some of the system delay error. It has been found[3] that the delay errors of receivers vary widely between manufacturers, and further that the error is dependent upon receiver tuning. In the NTSC Revised Signal Specifications of February 2, 1953, no attempt is made to correct for lf delay distortion in the receiver.

2. *Transmitter Sideband Filter:* The vestigial sideband filter used at the transmitter to suppress a portion of the lower sideband contributes heavily to the system delay distortion at frequencies below 3 mc (referred to the video signal). It is found[3] that a correction network applied at the video input to the transmitter affords substantial improvement in all receivers with general characteristics as shown in Fig. 1a in spite of individual receiver variations.

Application of Delay Correction to NTSC Color Television

The NTSC Revised Signal Specifications of February 2, 1953, call for an envelope delay at the transmitter relative to 0.1 mc of zero μsec up to a frequency of 2.5 mc; and then linearly decreasing to 4.3 being equal to 0.26 μsec at the subcarrier frequency of 3.579545 mc. A tolerance in delay of ±0.05 μsec relative to that at 0.1 mc is permitted.

Reference of the delay characteristic to the value at 0.1 mc implies correction at the transmitter for delay errors introduced by the vestigial sideband filter. Specification of delay characteristic above 2.5 mc implies correction at the transmitter for receiver hf cutoff characteristics, which for color receivers are expected to be similar to those for monochrome receivers due to similar requirements for associated sound carrier rejection.

The tolerance of ±0.05 μsec in the delay characteristic may be met with circuits of practical stability and is approximately equal to the residual errors in a compensated system. It may be noted that 0.05 μsec is approximately one-half picture element in the horizontal direction of the televised image. Correction of delay errors in the transmitted color television signal will result in improved picture quality as viewed both on color receivers and existing monochrome receivers, compared to uncompensated transmission.

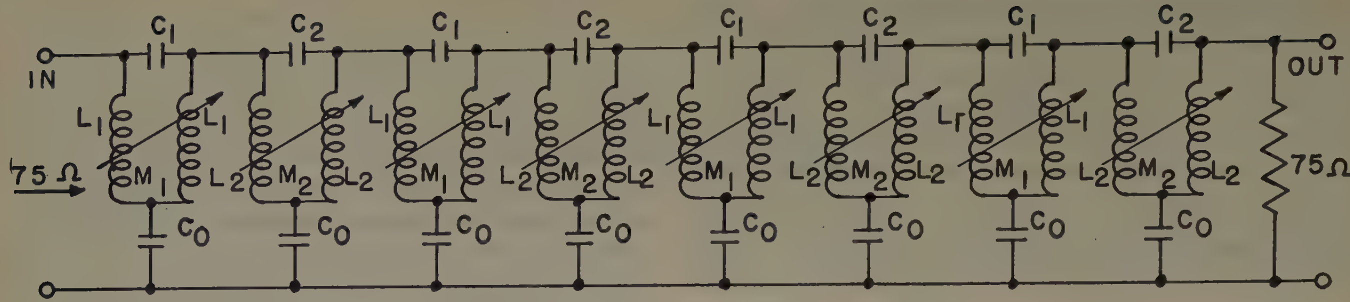
Correction of Delay Errors

While the actual delay errors are incurred, for the most part, in the RF circuits of the transmitter and of the receiver, it has been found that very effective compensation can be made through the application of phase correction networks to the video input signal of the transmitter. Fig. 2, following page, shows a delay equalizer composed of bridged-T sections which approximates the NTSC delay characteristic within the prescribed tolerances. The actual delay characteristic of this equalizer is shown in Fig. 3 on page 94.

Fig. 4 shows an equalizer used to correct the delay errors resulting from vestigial sideband transmission through a specific transmitter-sideband filter-receiver combination.[3] In any particular case, the delay characteristics of the transmitter together with its associated sideband filter must be ascertained, and an equalizer designed for the correction required to meet NTSC specifications.

Fig. 5,[3] shows the effects of delay equalization on the transient response of a specific transmitter-sideband filter-receiver combination. A similar improvement in performance of any uncorrected system may be expected when the delay characteristic of the NTSC specification is met by the transmitter.

The correction of delay errors over the hf portion of the receiver response is applicable not only to the hf components of the luminance signal, but also to the



$L_1 = 2.61\ \mu h$ $L_2 = 3.77\ \mu h$

$M_1 = 2.17\ \mu h$ $M_2 = 1.01\ \mu h$

$C_1 = 38.2\ \mu\mu f$ $C_2 = 245\ \mu\mu f$

$C_0 = 1700\ \mu\mu f$

Fig. 2—Delay equalizer for receiver high-frequency cutoff.

chrominance signal at the subcarrier frequency of approximately 3.6 mc. Delay error correction will improve the transient response of the chrominance channel; if delay errors existed, they would appear as poor color transient response with resulting color fringes at edges of objects viewed on the color receiver. For this reason, it is perhaps more important that delay errors be held to a minimum in NTSC color transmission than in monochrome transmission.

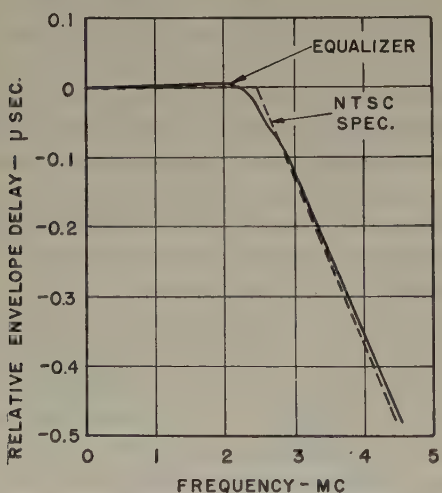


Fig. 3—Delay characteristic of equalizer of Fig. 2.

Time Coincidence of Signal Components

The Revised Specifications for Field Test of NTSC Compatible Color Television, dated February 2, 1953, set a tentative tolerance of $\pm 0.05\ \mu$sec on the time match of E_Y', E_R', E_G', E_B', E_Q', and E_I'. It is intended that this match be made at the 50 per cent point of a transition in the wave forms of the components of the radiated signal. Since the E_Y', E_Q', and E_I' signals are radiated with different bandwidths, they would not (without correction) be in time coincidence even if derived from E_R', E_G', and E_B' components which were generated in time coincidence. This follows from the discussion above on envelope delay, inasmuch as the slope of the phase-versus-frequency curve for the narrow band circuit would ordinarily be greater than that for the wide band circuit. The matrix and encoder units which generate E_Y', E_Q', and E_I' from E_R', E_G', E_B' must, therefore, contain delay equalizers to bring the output signals into time coincidence. Of course, the E_R', E_G', and E_B' signals derived from E_Y', E_Q', and E_I' available in the radiated signal would be in time

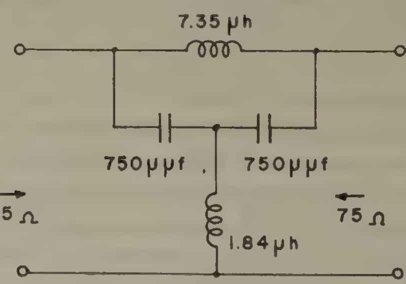


Fig. 4—Delay equalizer for vestigial sideband transmission.

coincidence if derived in circuits of similar bandwidth and phase characteristics. If, as would be done in a conventional color receiver, the bandwidths of the several circuits differ, there would be required further delay equalization in the receiver compensating for different delays in the receiver channels for E_Y', E_Q', E_I', E_R', E_G', and E_B'.

It has been found experimentally that picture degradation occurs, both in monochrome and in color receiv-

ers, when the signal components are not in time coincidence. In the case of the monochrome receiver, slight effects from the presence of the chrominance signal are least objectionable when the chrominance transitions are centered on the luminance transitions. Similarly, in the color receiver, spurious chrominance components in the luminance channel (arising mainly from system nonlinearities) are least objectionable when centered about the luminance transitions.

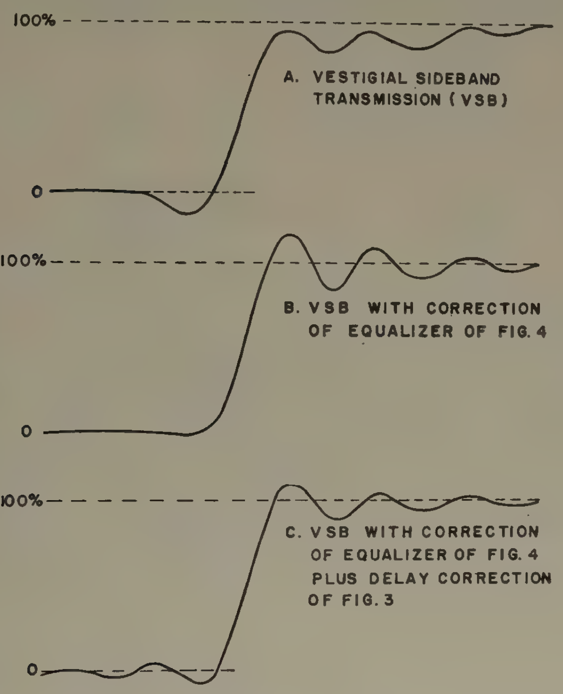


Fig. 5—Effect of delay equalizers on system transient response.

The tentative tolerance of 0.05 μsec corresponds to approximately one-half picture element, and is considered readily attainable in stable circuits and of insignificant effect on picture quality.

Addendum

Subsequent to the preparation of this paper, a modification to the delay specification was recommended by Panel 13 of the NTSC at its meeting on June 9, 1953. At its meeting of June 24, 1953, the NTSC approved the following revised specification of delay:

"Delay Specification:

A sine wave, introduced at those terminals of the transmitter which are normally fed the color picture signal, shall produce a radiated signal having an envelope delay, relative to 0.1 mc, of zero μsec up to a frequency of 3.0 mc; and then linearly decreasing to 4.2 mc so as to be equal to −0.17 μsec at 3.58 mc. The tolerance on the envelope delay shall be ±0.05 μsec at 3.58 mc. The tolerance shall increase linearly to ±0.1 μsec down to 2.1 mc and remain at ±0.1 μsec down to 0.2 mc. The tolerance shall also increase linearly to ±0.1 μsec at 4.2 mc."

The equalizer of Fig. 2 is not applicable to the delay characteristics of this revised specification; accordingly, a revised equalizer will be required in the video circuits of the transmitter to achieve conformance with this modification.

Effect of Transmitter Characteristics on NTSC Color Television Signals*

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Summary—**The radiated wave form of a fully-equalized color television transmitter is shown in the amplitude range which includes the subcarrier burst and the sync pulses.**

Three cases of saturated color bar transmission corresponding to different depths of modulation of the RF carrier are analyzed. It is shown that both the subcarrier and the luminance components are altered by the partial suppression of one sideband even in the idealized system. However, saturated colors are not usually present in average color scenes and the current monochrome standards for white level may be adhered to in color transmission.

Several sources of incidental phase shift of the subcarrier in the transmitter as a function of the modulation depth are pointed out.

Measurement procedures for the determination of incidental phase shift and differential gain are illustrated by actual oscillograms.

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Introduction

A COLOR TELEVISION signal generated according to the NTSC Field Test Specifications is equivalent in many ways to a standard monochrome signal. For the transmission of the additional information required for the production of images in natural color two new features have been added: a color burst or reference signal for the color information and a subcarrier having an amplitude which exceeds white level for certain color composition.

Since monochrome television standards require vestigial sideband transmission and a modulation level for white as low as 15 per cent of peak carrier it is worthwhile to investigate the performance of monochrome transmitters when radiating compatible color signals.

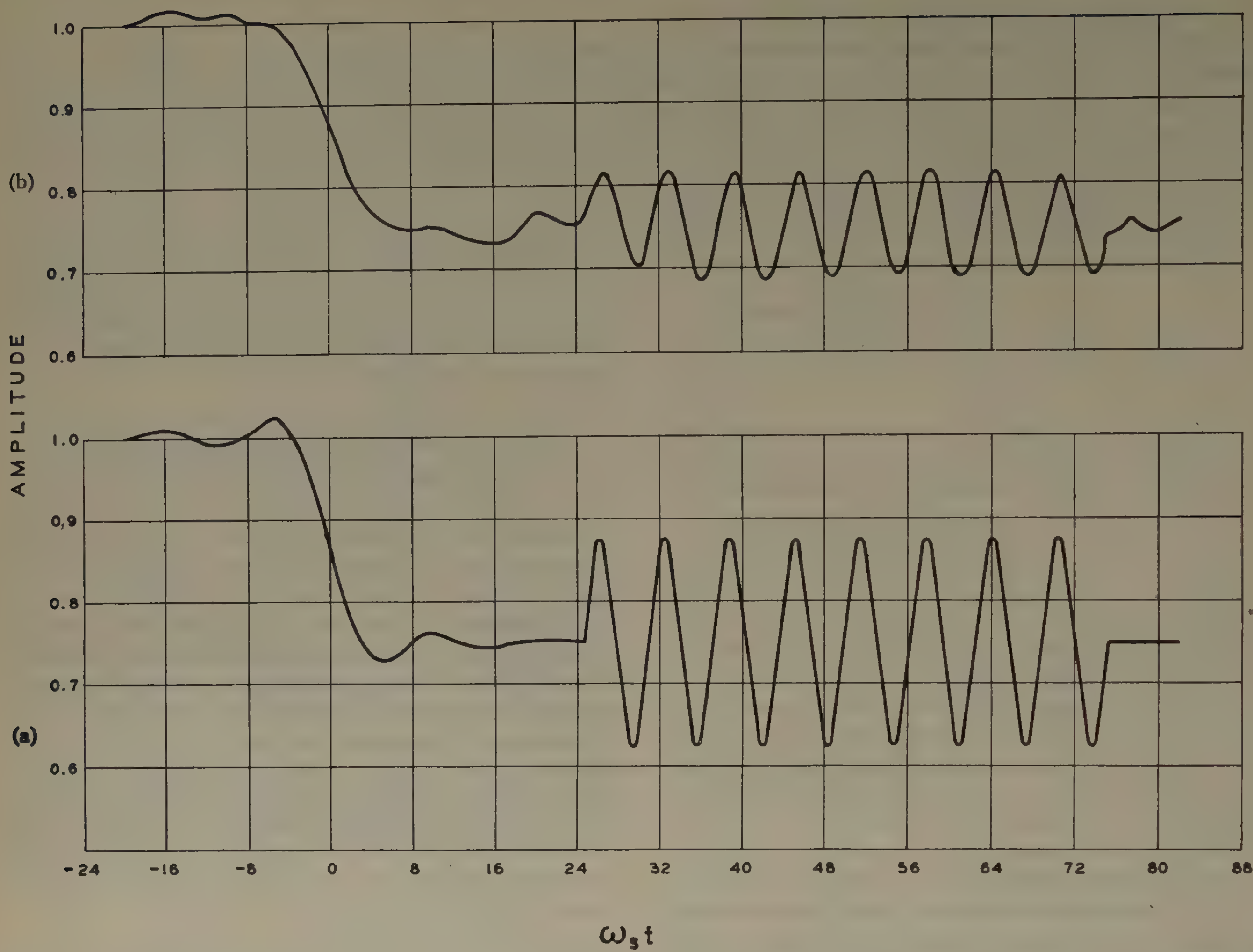


Fig. 1—Horizontal sync, back porch, and burst wave forms. (a) Modulating signal. (b) Envelope of radiated wave form. $\omega_s = 2\pi \times (3.58 \times 10^6)$.

It is the purpose of this paper to show theoretically and experimentally the waveshapes encountered in the synchronizing region with color signals, the effect on color signals of operation with increased demand in the white direction, and the shift in phase of the color subcarrier as a function of the position of the modulation characteristic.

Envelope of the Radiated Synchronizing Wave Form

The theoretical envelope of the radiated synchronizing wave form in color transmission under ideal conditions is of interest for monitoring purposes. Two monitoring arrangements are in general use: (1) a linear diode applied to the transmission line at the output of the vestigial sideband filter, and (2) a monitor having receiver-type amplitude response also applied at the output of the filter. The wave form may also be observed on an oscilloscope with a bandwidth that includes the carrier frequency and sidebands of the transmitter.

The envelope may be expected to differ from the wave form of the video modulating signal in the following respects:

(1) The amplitudes of frequency components in the single sideband region of the vestigial sideband filter characteristic are attenuated approximately 6 db.

(2) Quadrature distortion is introduced by the vestigial sideband filter.

(3) Phase and amplitude distortion occur in an adequately compensated transmitter.

(4) Nonlinearity of the modulation characteristic and other characteristics may introduce noticeable wave form distortion.

In the theoretical treatment only items (1) and (2) may be considered without undue complication. Items (3) and (4) must be identified with particular transmitters. Fig. 1(b) is the calculated envelope of that portion of the radiated RF signal containing the trailing half of the horizontal sync pulse, back porch, and burst.

The predistorting delay characteristic of the proposed NTSC standards for the equalization of receiver cutoff delay distortion modifies the wave form of the input video signal to the transmitter. The effect is susceptible to calculation but is much more simply treated

experimentally. For purposes of calculation an idealized vestigial sideband characteristic shown in Fig. 2 is assumed. The trailing edge of horizontal sync is shown as a step function restricted in bandwidth to 2.2 mc, a representative value for a synchronizing wave form. Other details of the input modulating wave form are shown in Fig. 1(a).

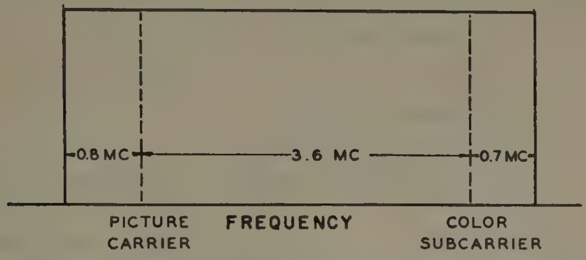


Fig. 2—Idealized amplitude characteristic of transmitter.

Several conclusions may be drawn. In the first place, quadrature distortion plays a minor role, as may be anticipated since the greatest depth of modulation for the peaks of burst in the white direction is 63 per cent of peak carrier.

The decay of the sync pulse of the radiated wave is increased about 1.5 times over the modulating signal due to the reduction of high-frequency components.

The space originally present between the back edge of sync and the beginning of the burst is not excessively filled in by transient excursions. A precursory cycle of the burst is discernible but the amplitude is low and a similar transient disturbance is present following the conclusion of the burst. Burst amplitude is reduced 50 per cent due to single sideband transmission.

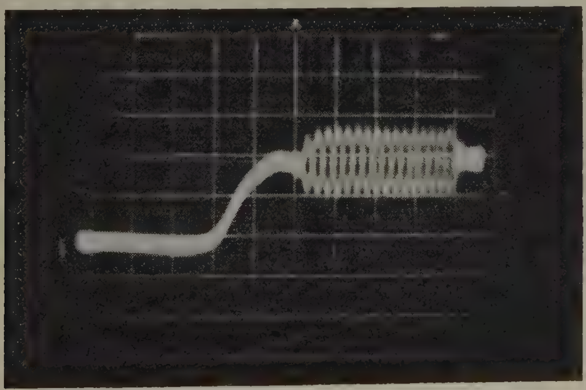


Fig. 3—Without receiver correction.

The effect on the burst of pre-compensation for receiver cutoff delay distortion[1] is illustrated in the experimentally determined waveshapes in Figs. 3 and 4 which were observed by the linear diode method. Two additional cycles of diminished amplitude are added before and after the burst and the entire wave form is advanced approximately one-half cycle at 3.58 mc.

[1] According to the NTSC Field Test Specifications dated Feb. 2, 1953. In the final proposed standards dated July 21, 1953, minor variations in the delay specifications were approved by the NTSC. These changes do not affect the conclusions drawn here.

Relative Phase Shift

There are two types of phase distortion to be considered in a color television system. Phase distortion that results in both color burst and color picture information being shifted together has a small effect in comparison with the errors in color reproduction caused by a variation in the phase of the subcarrier as a function of its position in the amplitude range from burst toward white level.

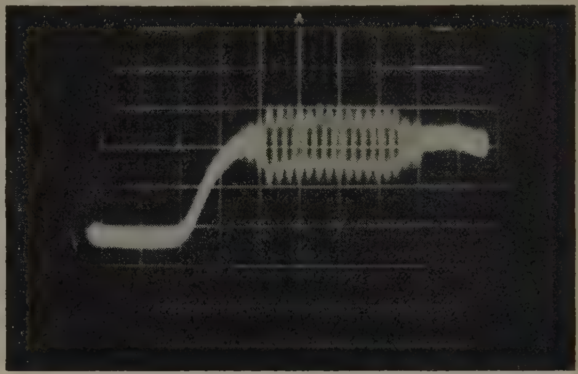


Fig. 4—With receiver correction.

There are at least three known causes of phase shift over the amplitude range. They are diagonal clipping, parallel-path systems, and variable impedance elements. An example of diagonal clipping is shown in Fig. 5. An analysis of such a wave will show that the fundamental component has been shifted a small amount. For the case of the color subcarrier, such a wave form can be obtained only where the bandwidth is great enough to pass the harmonics. After bandwidth limitations have removed the harmonics, the sine wave is restored at slightly reduced amplitude but with the phase shifted.

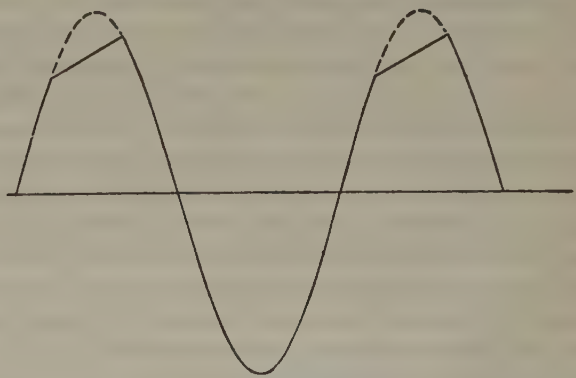


Fig. 5—Diagonal clipping.

The magnitude of the phase shift produced is not a function of the amount of clipping but rather of the tilt produced. In television transmitters actual clipping may occur in the white direction but only compression will normally exist in the sync direction. It should be recognized that clipping is just a special case of compression and either can be accompanied by phase shift.

The second cause of phase shift—parallel paths—exists to some extent in nearly every circuit containing an active element. The mechanics involved can be expressed simply as a signal made up of two components, one of which differs from the other. This is more likely to occur in studio equipment where, for example, a steady subcarrier signal could combine with a video signal through stray coupling. This could produce both amplitude and phase variations and the amount would be a function of the amplitude and phase of the desired signal. A similar problem can be expected at the transmitter where the video signal is carried by tubes in parallel. If the delay through all paths is not equal at all amplitude levels, the combined signal will show phase variations between color burst and color picture information.

The third cause, variable impedance, is exemplified by a generator feeding a network involving reactances and a load. A change of either generator or load impedance may result in a change in over-all phase shift. For transmitters, which are normally driven into grid current in the sync region, a radical impedance change occurs and phase distortion may result.

In order to test transmitters for this latter type of phase shift, a test set-up consisting of three units, a signal generator, a calibrated phase shifter, and an oscilloscope, was used. The generator produced a synthetic horizontal synchronizing pulse placed on a blanking pedestal and a subcarrier[2] signal of variable amplitude added to the composite pulse signal as shown in Fig. 6. A subcarrier reference signal was also available. This reference signal was fed to the phase shifter providing continuously variable phase from zero to 360 degrees which was then used for horizontal deflection of the oscilloscope. The accuracy of this phase shifter in this type of service was of the order of ± 1 degree.

The synthetic sync pulse, with no subcarrier added, was connected to the input of the transmitter being tested and the RF output—suitably detected—was used for vertical deflection of the oscilloscope. The generator and transmitter were adjusted for the desired operation and then a small amount of subcarrier was added to the input signal. Since the horizontal deflection of the oscilloscope was produced by sine waves and the vertical deflection contained identical sine waves at three different levels (picture, back porch, and tip of sync), three simple Lissajous figures were produced. Each could be varied from a circle, or an oval, to a slanting straight line by varying the phase shifter. The phase required to just close an ellipse to a line is very critical, so this was the indication used throughout the measurements. Considerable information is available in such a display. First, if a different reference phase is needed to close one of the ellipses, a phase shift at that amplitude level is indicated. Also, if the slope of the line upon closing is different, amplitude compression is indicated. Furthermore, relatively small effects can be measured. For example, some transmitters employ back porch clamping for dc insertion. Unless this clamping has negligible effect, the oscilloscope display will show a separate line during clamp time which can be measured.

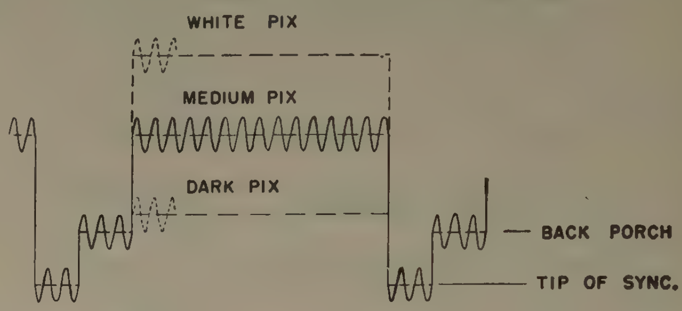


Fig. 6—Test signal for phase measurement.

The equipment and method just described were used to measure the subcarrier phase characteristic of several transmitters. The primary results of the tests are summarized in Table I. By changing the blanking pulse amplitude at the test generator, the test signal could be moved throughout the picture portion of the amplitude range. This accounts for the terms "White pix," "Medium pix," and "Dark pix," used in the table. The fact that the phase at back porch is always marked zero degrees should not be construed to mean that the phase did not change at this level but rather that this level was chosen as a reference for all measurements. Also noteworthy is the fact that picture level has a small effect on the phase shift in the sync region.

From the data shown in Table I it can be concluded that normal monochrome adjustment procedures have not generally produced operation adequate for entirely satisfactory transmission of color signals; also the color burst and bright saturated yellows are located in the two regions of the amplitude range of a transmitter which are most likely to produce phase shift.

Depth of Modulation and the Effect on Color Reproduction

Theoretical Investigation

Compatibility of color and monochrome television is improved if peak white in each transmission corresponds to the same depth of modulation in the radiated signals. Appreciable discrepancies in the depth of modulation for white result in shifts in the average background brightness on the receiving screen and a change in the contrast range of the images.

The present rules governing monochrome transmission establish the level corresponding to peak white between 10–15 per cent of peak carrier. The same provi-

[2] A 3.89-mc color subcarrier was in use at the time these tests were made. The change to 3.58 mc is not sufficient to materially change the results.

TABLE I

COLOR SUBCARRIER PHASE SHIFT IN TELEVISION TRANSMITTERS

(Transmitters adjusted for normal monochrome operation)

Transmitter	Detected *RF* signal								
	Dark Pix			Medium Pix			White Pix		
	Sync Tip	Back Porch	Pix	Sync Tip	Back Porch	Pix	Sync Tip	Back Porch	Pix
1	0°	0°	2°	3°	0°	5°	5½°	0°	5°
2	32	0	0	27	0	0	36	0	0
3	20	0	0	22	0	−1	25	0	−3
4	20	0	−3	28	0	−12	25	0	−18
5	7½	0	−1½	10	0	−4½	12	0	−15
6	26	0	−2	25	0	−1	25	0	−1

Note: The use of zero degrees at black level throughout the table means only that this level was used as a reference and not that it did not differ for various adjustments.

sion has been set up for color transmission in the NTSC Color Field Test Specifications (February 2, 1953). Under this condition the signal peaks corresponding to bright saturated yellow and cyan in the white direction cannot be accommodated by the modulation range of the transmitter and either over-modulator or peak clipping ensues. The envelope of the receiver RF signal is therefore not an exact replica of the video modulating signal.

Furthermore, the fact of single sideband transmission of the color signal introduces a certain amount of distortion. Calculated data for the evaluation of the effects of over-modulation and single sideband transmission are presented in the following analysis.

An appropriate although somewhat extreme signal for transmission analysis is that corresponding to the familiar color-test chart consisting of vertical bars of green, yellow, red, magenta, blue, and cyan. Certain simplifying assumptions will be made in dealing with the modulation process in order to render an otherwise complicated, nonlinear process amenable to calculation. The concern is with the steady state and not with transient intervals during transition between colors.

Three different depths of modulation are of interest:

Case 1. Modulation level for white, 28 per cent; for cyan and yellow, 12½ per cent. This case is not in accordance with the Color Field Test Specifications but it is included here for comparison. White level must correspond to no less than 28 per cent of carrier if the peaks of cyan and yellow are not to extend lower than 12½ per cent of carrier in the linear modulator.

Case 2. Modulation level for white, 12½ per cent; peaks of cyan and yellow clipped at zero carrier. This is the median value of the NTSC Specification which states that the maximum white level is not more than 15 per cent nor less than 10 per cent of the peak carrier amplitude. A linear modulation characteristic is assumed.

Case 3. Modulation level for white, 12½ per cent; peaks of cyan, green, and yellow clipped in the video signal such that the peaks in the RF signal extend only to 12½ per cent of maximum carrier. This assumption covers a transmitter that cannot be modulated much below 12½ per cent but is linear to that point.

The character of the signal at two points in the television system are especially significant in each of the three cases. First, the envelope of the carrier signal at the input of the receiving detector may be compared with the distortionless video wave form of the color-bar pattern. For this comparison it is assumed that the RF carrier is attenuated 6 db in the receiver and that the transmitted sideband corresponding to the steady state of the color subcarrier is not attenuated. Second, the red, green, and blue signals applied to the tricolor viewing tube affords ultimate comparison of the three types of modulation.

Basically, the problem calls for the calculation of: (1) the amplitude of the beat note between the picture carrier and sideband corresponding to the color subcarrier, and (2) the magnitude of the dc component determined by the depth of modulation just before detection. The phase of the color subcarrier relative to burst does not enter. Several investigators[3] have analyzed the beat note envelope in detail and the results with modifications required by the present problem are given in Appendix 1.

Fig. 7 shows the envelope of the RF carrier at the input of the receiving detector for the six principal colors and the three types of modulation. The luminance and chrominance signals for blue undergo little change for any case whereas yellow, which is clipped off to the greatest extent, is considerably affected.

Signals at the input to the tricolor viewing tube are shown in Fig. 8. It is concluded from these charts that there is a tendency in single sideband transmission of colors for yellow to be reduced in saturation and brightness as modulation conditions require more clipping of the peaks in the white direction. All other colors exhibit a decrease in brightness without a change in saturation comparable to that shown for yellow.

[3] F. M. Colebrook, "The frequency analysis of the heterodyne envelope," *Experimental Wireless*, vol. 9, pp. 195–201; April, 1932.

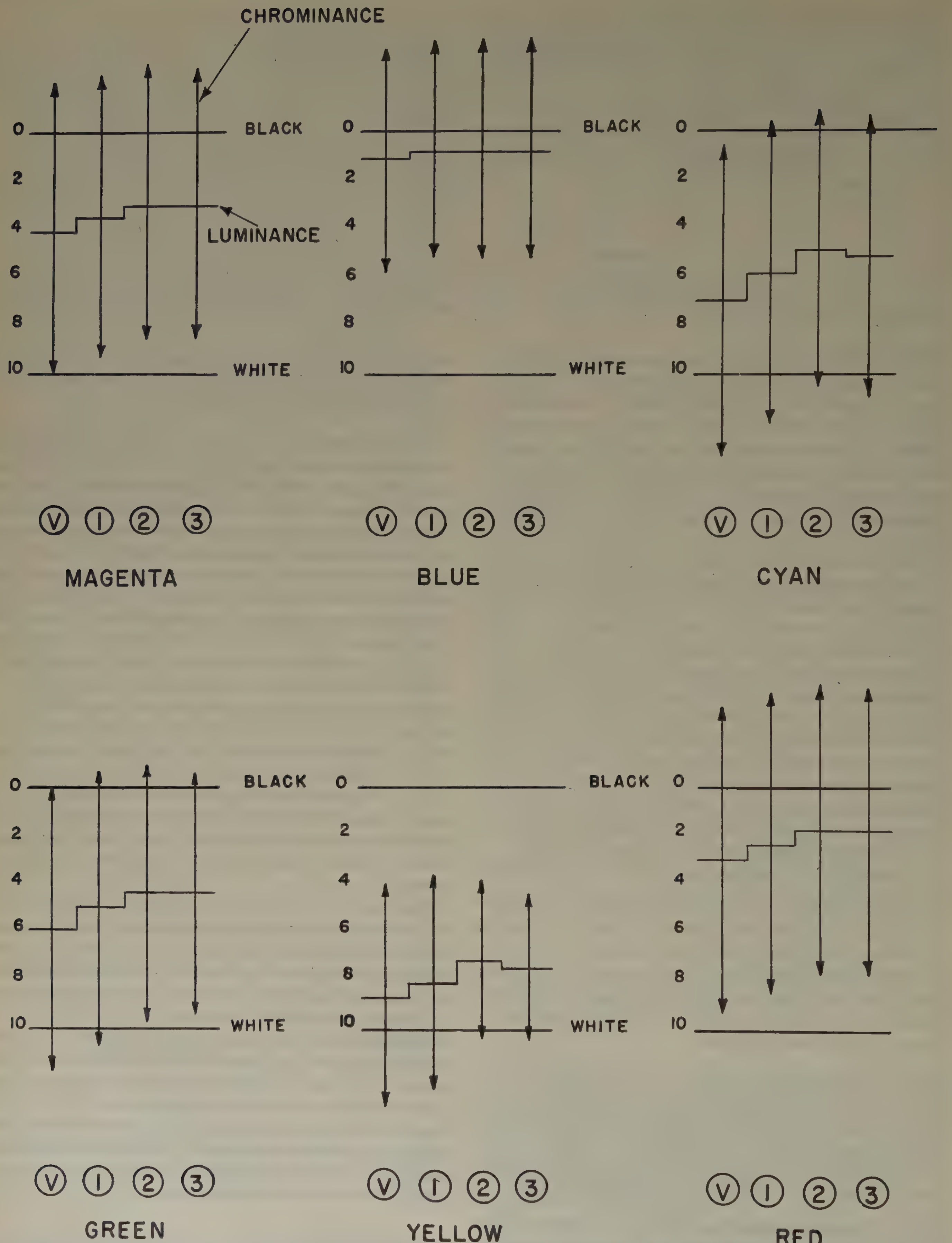


Fig. 7—Envelope of the color-bar best signal at the input of the receiving detector for modulation cases (1), (2), and (3). (V) denotes modulating signal. Excursion of the chrominance signal is indicated by double arrows. Luminance components are shown in full lines.

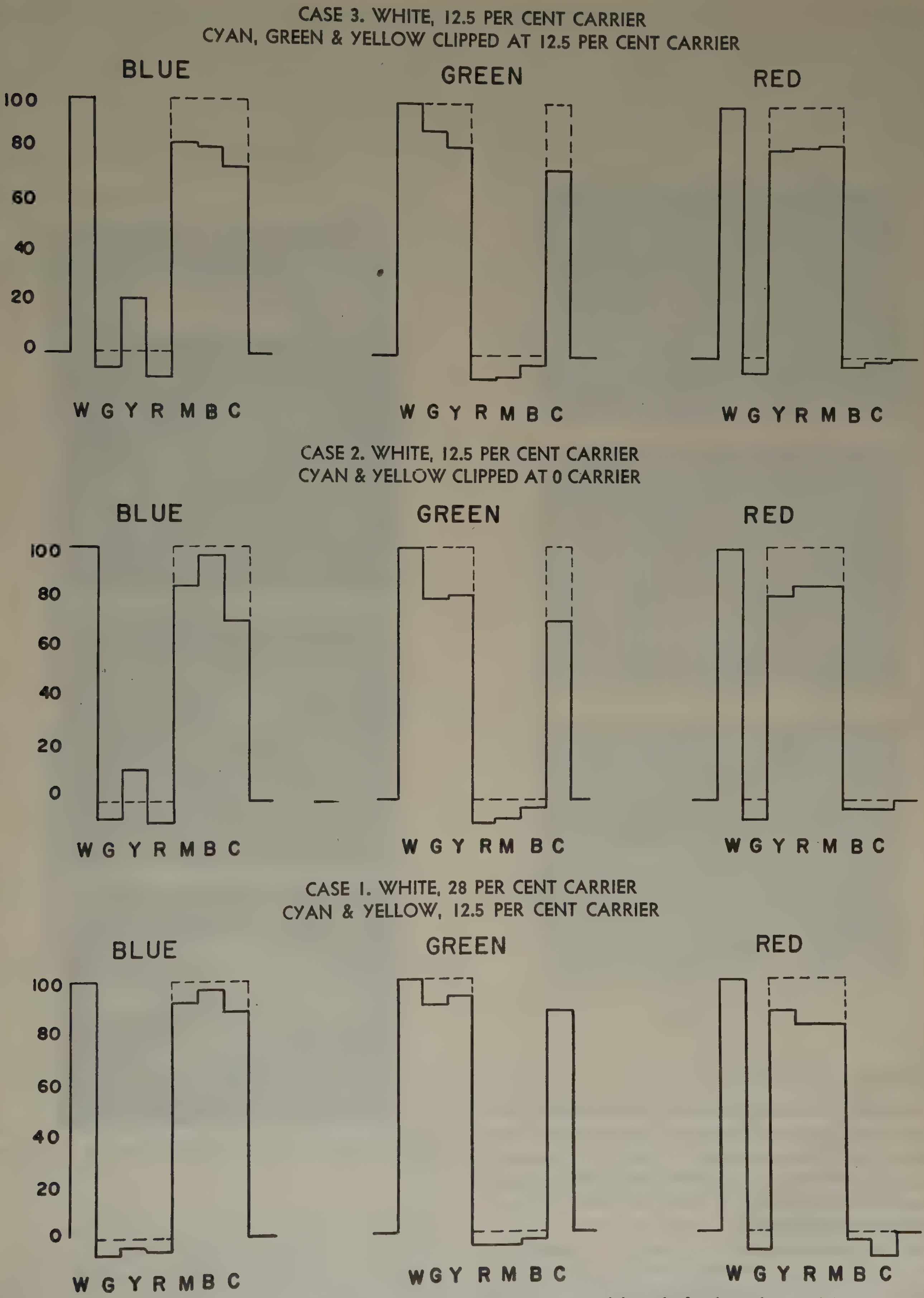


Fig. 8—Signals applied to the blue, green, and red inputs of the tricolor receiving tube for the various modulation cases. Undistorted signals are shown in dotted lines.

The inadvisability of adhering strictly to the NTSC modulation specifications of February 2, 1953, for the transmission of the color-bar test chart has been recognized in practice. Distortions shown in Figs. 7 and 8 are largely avoided by a reduction of about 25 per cent in the amplitudes of all chrominance and luminance signals in the modulating signal except the signals corresponding to white and the gray scale. White level of the modified signal is then retained at $12\frac{1}{2}$ per cent of peak carrier.

In the transmission of useful studio and out-of-doors scenes the saturated colors of the color-bar test chart are not usually present. With chrominance signals of moderate amplitude, peak limiting near zero carrier does not occur and negligible distortion results from operation according to the NTSC specification of 10–15 per cent modulation of the peak RF carrier for white.

Fig. 9—Test signal.

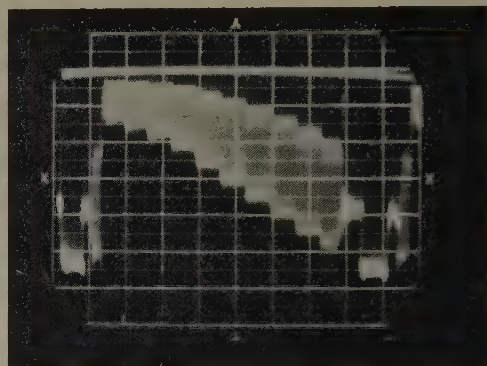
Experimental Investigation

The modulation characteristic of any television transmitter is an S-shaped curve. By inherent design or by the addition of special correctors the major portion of the amplitude range may be made quite linear; however compression is inevitable at cut-off, and in the sync region it can be expected.

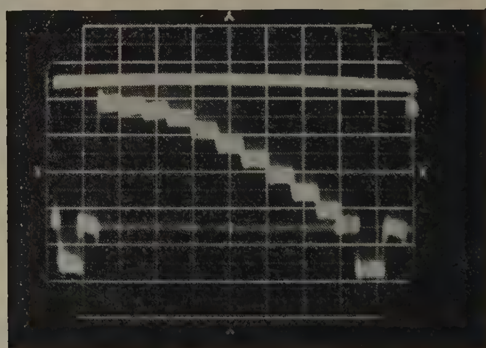
As has been pointed out, a transmitter radiating a color signal in accordance with the NTSC signal specifications will have demand requirements not encountered with monochrome signals. Linearity is also much more important since it can be an indication of phase shift or result in a change of saturation of colors.

For color television signals, it is important to measure the transmitter not only at low frequencies—which carry nearly all of the luminance information—but also at the color subcarrier frequency. Measurements have shown that systems that are quite linear at, say, 150 kc may be quite nonlinear at 3.58 mc.

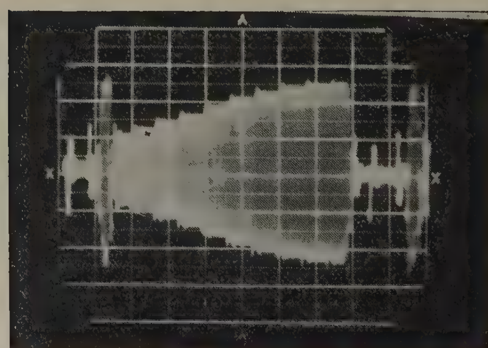
A test system that has evolved makes use of a special test signal. To sync is added a "stair-case," as shown in Fig. 9(a), and then a small amount of 3.58 mc is added to the steps to produce the signal shown in Fig. 9(b). After transmission through the system being tested, the video signal can be band-limited by a low-pass filter and observed on an oscilloscope to see if the steps are still of uniform height. This checks the low-frequency linearity. By exchanging the low-pass filter for a high-pass filter the low-frequency components will be removed, which



(a)



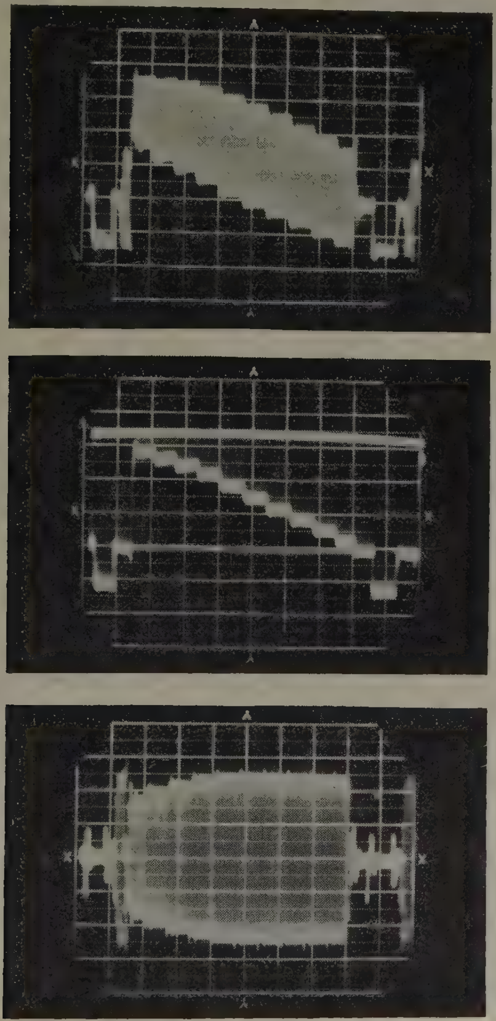
(b)



(c)

Fig. 10—Test signal through a nonlinear transmitter. (a) Composite signal. (b) Low-frequency components. (c) High-frequency components.

makes it very simple to observe and measure the differential gain at the color carrier frequency. Fig. 10 shows (a) the composite output signal, (b) the low-frequency component, and (c) the 3.58-mc component of a nonlinear transmitter. Fig. 11 shows the same information for a relatively linear transmitter. For the examples shown, the amplitude of the 3.58 mc added to the "staircase" is higher than would normally be used for measuring differential gain.



(a)

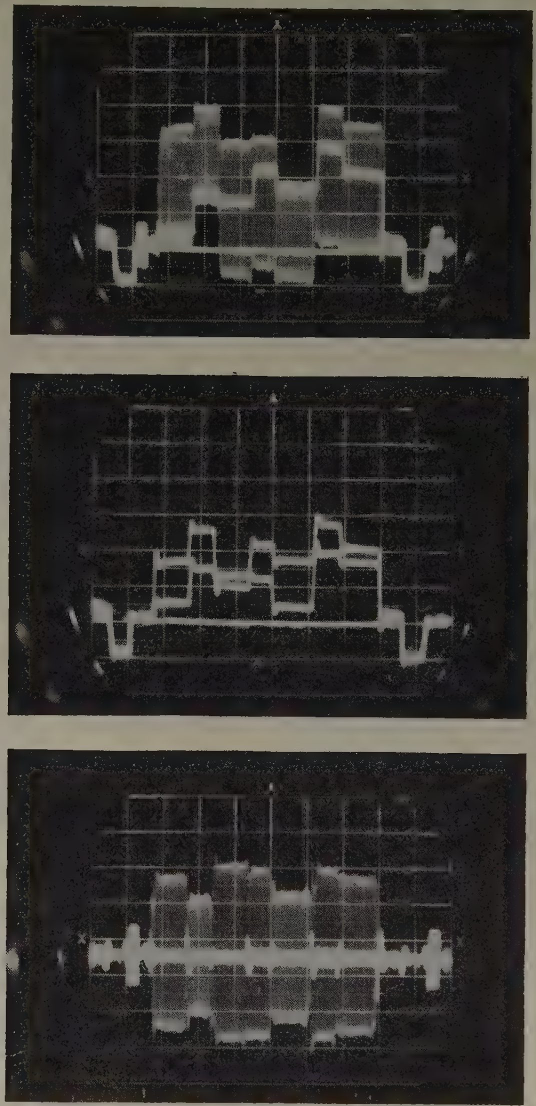
(b)

(c)

Fig. 11—Test signal through a linear transmitter. (a) Composite signal. (b) Low frequency components. (c) High frequency components.

This test signal can be used further to provide phase-shift information. A measure of the relative phase of the 3.58-mc sine waves on each of the steps will show the phase shift as a function of location in the amplitude range of a system. As an example of the inconsistencies that may be encountered, the two systems shown in Figs. 10 and 11 show entirely different linearity characteristics, yet in each case the maximum phase shift from the first step to the last is about 3 degrees.

The method used for measuring relative phase for the data presented is a cancellation system. An accurately calibrated phase shifter, with adjustable output amplitude, is used to obtain a signal which, when added to the signal being tested and observed on an oscilloscope, exactly cancels the fundamental component of the color signal being measured. The accuracy of the phase shifter is ±1 degree, however, variations across any single color patch in a composite picture are usually large compared with this, so no such accuracy can be attached to the final results.



(a)

(b)

(c)

Fig. 12—Analysis of a color signal. (a) Composite video signal. (b) Low-frequency components. (c) High-frequency components.

A method similar to that just described for linearity tests can be used for measurements on an actual color signal. If a color-bar signal, such as is shown in Fig. 12(a), is passed through a low-pass filter, the chrominance information will be lost as shown in Fig. 12(b), so that luminance values can be measured.[4] If a high-pass filter is used, only the chrominance information will be passed, as shown in Fig. 12(c), so that amplitude and relative phase can be measured. Using this method of measurement, four types of transmitter operation were examined.

[4] The test chart included a gray scale in addition to color bars.

In considering how to operate a transmitter with color signals, two alternatives are apparent. Knowing that a fully saturated yellow will produce a video voltage 33 per cent higher than white, the modulation at white level could be reduced accordingly so that the high peak-swings would just produce a normal 85 to 90 per cent modulation. This is incompatible because, by reducing the average modulation as compared to monochrome, the service area of the station would be decreased. A second alternative—and this is the method proposed by the NTSC—would be to operate with white level producing normal modulation and accept the degradation caused by clipping or compressing signals extending above white level.

The transmitter station can use either of two systems and still conform to the NTSC signal specifications. The white level modulation can be set at 10 to 15 per cent of peak carrier and the transmitter itself depended upon to compress or clip off the high amplitude peaks, or a clipper can be installed which has a known characteristic. Note that for maximum effectiveness, this clipper should not be followed by band limiting circuits which pass only the fundamental component of the clipped waves.

One other case that was investigated carries the above situation to an extreme. For this case the clipper was made to clip off about 10 per cent of peak white. This would be an improper adjustment and is included only for information.

The results of these tests are shown in Table II. It should be emphasized that this data is for the extreme case involving synthetically produced colors of maximum saturation. All measurements were made with a double side-band detector ahead of the vestigial sideband filter.

TABLE II

EFFECT OF CLIPPING ON COLOR BARS

Color	No video clipping. White at 87% mod.		Clip video at white. No transmitter clipping		Clip video 10% into white. No transmitter clipping	
	Reduction in		Reduction in		Reduction in	
	Chrominance	Luminance	Chrominance	Luminance	Chrominance	Luminance
Green	20%	12%	7%	14%	26%	22%
Yellow	47	16	35	24	69	37
Red	4	2.5	0	15	8	15
Magenta	4	9	0	13	14	18
Blue	0	0	0	0	0	0
Cyan	29	14	19	18	42	26
White	—	12	—	19	—	48

Note: Above data is based on blue being correct in each case.

From the point of view of picture quality it is probably more important to maintain the ratio between chrominance and luminance than to have just one of these correct. On this basis it is apparent that small amounts of clipping may not cause appreciable defects in many pictures.

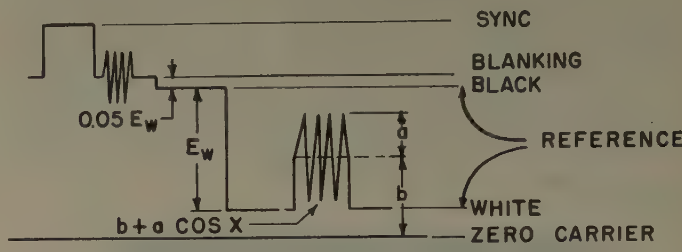


Fig. 13—Color-bar signal.

APPENDIX I

Steady-State Envelope of Color-Bar Signal at the Input of the Receiving Detector

An RF carrier, cos y, modulated by a subcarrier and luminance component $(b+a \cos x)$ as illustrated in Fig. 13 is given by

$$e_0 = b \cos y + \frac{a}{2} \cos (y - x) + \frac{a}{2} \cos (y + x). \quad (1)$$

After elimination of the lower sideband and attenuation of the picture carrier by 6 db in the receiver, (1) becomes

$$e_1 = \frac{b}{2} \cos y + \frac{a}{2} \cos (y + x). \quad (2)$$

Equation (2) represents a heterodyne signal and has the following envelope to which the linear receiving detector responds:

$$E = \frac{b}{2} (1 + r^2 + 2r \cos x)^{1/2} \quad (3)$$

where $r = a/b$.

The expression E has been expanded by Vigoureux in a form that converges more rapidly for values of $r \leqq 1$ than the simple binomial expansion of the quantity.[8] The result is

$$(1 + r^2 + 2r \cos x)^{1/2} = a_0 \left(1 + \sum_1^{\infty} m_n \cos nx\right) \quad (4)$$

where

$$a_0 = 1 + \frac{r^2}{2^2} + \frac{1^2}{2^2 \cdot 4^2} r^4 + \frac{1^2 \cdot 3^2}{2^2 \cdot 4^2 \cdot 6^2} r^6 + \cdots \quad (5)$$

$$= \frac{2}{\pi} (1 + r) \int_0^{\pi/2} \sqrt{1 - r^2 \sin^2 \phi d\phi}$$

(a complete elliptic integral of the second kind which is extensively tabulated)

where $2r/(1+r) = k^2$.

$$a_0 m_1 = r \left\{1 - \frac{r^2}{8} - \sum_{m=2}^{p=\infty} \frac{1 \cdot 3 \cdots (2p - 3)}{2 \cdot 4 \cdots 2p}\right.$$

$$\left.\cdot\frac{3\cdot 5\cdots(2p-1)r^{2p}}{4\cdot 6\cdots(2+2p)}\right\}. \qquad (6)$$

The second and higher harmonic terms of (4) are outside of the band of transmitted frequencies.

Equation (3) becomes

$$E = \frac{ba_0}{2} + \frac{ba_0m_1}{2}\cos x. \qquad (7)$$

a_0 and m_1 have been calculated by Colebrook. The results appear in Fig. 14.

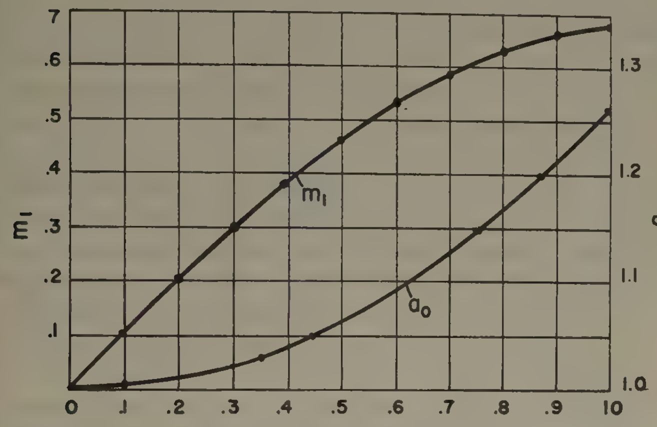


Fig 14—Values of a_0 and m_1 as a function of r.

The constants r and b are determined for a particular color bar by solution of the signal equation given in the NTSC Field Test Specifications,

$$\begin{aligned} E_M = E_Y' &+ 0.593E_G^{1/\gamma}\sin(\omega_s t - 119.5°) \\ &+ 0.632E_R^{1/\gamma}\sin(\omega_s t - 256.5°) \\ &+ 0.447E_B^{1/\gamma}\sin(\omega_s t - 12.5°). \end{aligned} \qquad (8)$$

Adjustment of the amplitudes of the chrominance and luminance components of the color are made for setup (5 per cent of the difference between black level and white level) and the proper modulation depth according to the case.

It should be noted in (7) that if only a monochrome halftone at carrier level "b" is transmitted, no distortion results in the received signal since $a_0=1$. The factor 1/2 is introduced by the attenuation of the receiver for the RF carrier. In single sideband transmission the presence of a chrominance component generates an additional dc component that always raises the carrier level of the luminance component. This is equivalent to a reduction in the detected signal which is measured from black level.

The amplitude of the chrominance component is always reduced in the process of single sideband transmission by a factor a_0m_1 according to (8). The maximum reduction of 15 per cent occurs when the luminance component equals the peak amplitude of the chrominance component ($r=1$).

Appendix II

Clipped Waves

In modulation Case 2 the peaks of yellow and cyan are limited in the white direction and in Case 3 the green subcarrier is also limited. The assumption is made here that the nonlinear process involved in over-modulation can be approximated by assuming that the RF carrier is modulated by a clipped video signal.

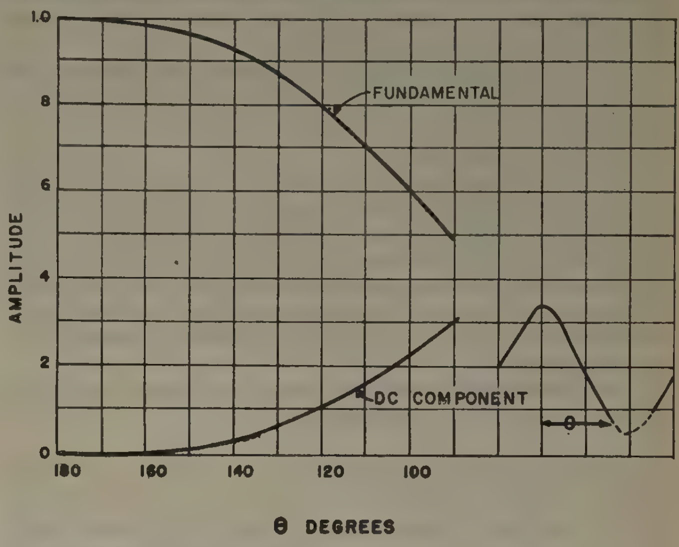


Fig. 15—Fundamental and dc components of a clipped sine wave.

In Fig. 15 the clipping level defines an angle θ. The Fourier series approximation of the clipped cosine wave is given by

$$E_2 = b' + a'(b_0 + b_1\cos x + \cdots + b_n\cos nx). \qquad (9)$$

where

$$b_0 = \frac{1}{\pi}\sin\theta + \left(1 - \frac{\theta}{\pi}\right)\cos\theta$$

$$b_1 = \frac{\theta}{\pi} - \frac{1}{2\pi}\sin 2\theta.$$

$b_2\cdots b_n$ correspond to harmonics which are not transmitted. Under conditions of the present problem

$$E_2 = (b' + a'b_0) + a'b_1\cos x$$

which has the same form as the modulating signal in (1). When $(b'+a'b_0) > a'b_1$, (3) is changed to the form

$$\frac{a'b_1}{2}(1 + r^2 + 2r\cos x)^{1/2}$$

where

$$r = \frac{b' + a'b_0}{a'b_1}$$

so that Vigoureux's series development may be used.

Acknowledgment

The authors wish to express their appreciation to Mrs. K. J. Rupprecht for her numerical calculation of Curve B, Fig. 1.

Color-Carrier Reference Phase Synchronization Accuracy in NTSC Color Television*

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Summary—**The results of an evaluation of the capabilities of the NTSC color-carrier reference signal (the color burst) show this new color television synchronizing signal to be more than adequate; information inherent to the signal permits performance far in excess of that achieved by conventional circuits.**

Phasing information inherent to the burst is considered first with particular regard to measures of accuracy, the required amount of integration, and the extent of the spectral region necessary to translate the burst information.

Properties of elementary passive and active circuits for using the burst in receivers are described along with a determination of the limits of burst synchronization performance for these circuits.

Fundamental considerations in the theory of synchronization show that better performance is obtainable with two-mode systems.

Properties of two-mode systems are considered and lead to an evaluation of the limits of synchronizing performance permitted by the color burst.

The mathematical derivations necessary to support the discussion are presented in the Appendixes.

NTSC COLOR television adds color to a monochrome picture by means of a narrow-band, frequency interleaved carrier color signal which carries one component of the color information in its phase, and another component in its amplitude. It is customary to provide a phase reference in the transmitted signal in order that receivers shall be able to measure the instantaneous phase angle of the carrier color signal so as to reproduce the desired color. This is accomplished by transmitting a short burst of oscillations at color subcarrier frequency during line retrace intervals,[1] at a reference phase which corresponds to the $(Y\text{-}B)$ axis.[2]

The color burst carries phasing information. This paper shows how much phasing information is contained in the color burst, and how it may be used.

Analysis of the factors limiting performance shows that, even under extreme conditions of interference and of stabilization requirements, the burst contains adequate information to provide a reliable color-carrier reference signal; in fact, the amount of phasing information in the color signal appears adequate enough so that a customer-operated control relating to color sync should be unnecessary on NTSC color television receivers. Analysis shows that presently used sync instrumentation systems appear capable of meeting but not necessarily exceeding a reasonable measure of the above requirements. However, information existing in the *signal* permits substantially better performance. The real limits of performance and sync systems which more fully utilize the signal information are discussed in this paper. Because of the excess of existing information, a variety of types of circuits can be used.

Several questions may be asked with regard to the amount of phasing information contained in the color burst and its application to provide a reference signal for color demodulation. These are: (a) How closely can the color-carrier reference signal be maintained to the true value, when signals are strong (and hence noise-free) and after transient effects have subsided? (b) How closely can the color-carrier reference signal be maintained in the presence of noise interference? (c) How long will a system or circuit designed to give satisfactory operation on (a) and (b) require to reach a stable mode of operation when stations are switched or a receiver is turned on? (d) How much performance is required in (a), (b), and (c)?

Of these questions, (d) is the most difficult to answer precisely; it depends on many subjective factors and may be obscured by temporary equipment difficulties. In order to provide a standard of comparison for use in this paper, a conservative (pessimistic) estimate has been made, based on past experience.

The answers to the questions are as follows:

(a) With a strong (clean) sync signal, the color-carrier reference signal may be maintained as closely accurate as desired, independent of other factors; in the presence of noise, the *average* phase may be maintained as closely as desired, independent of the required integration and transient characteristics; for example, designs presented later show how the static or average phase of the color-carrier reference signal may be controlled to within five degrees of the true value. Expressed as a time value this is an accuracy of approximately six mμsec. This phase accuracy implies a color fidelity probably substantially better than can be distinguished by the observer.[3]

(b) *The real limitation on performance* is thermal-noise interference, since this type of interference is the most difficult type to reject. It *is* rejected, however, *to any selected measure of reliability* by integration of the synchronization timing information over a suitably long period. Either of two basic types of integrators may be used. These are, one, passive integrators, and two, frequency-and-phase-locked self-oscillating integrators. The analysis presented in this paper shows that, under severe assumptions on the requirements of phase stability and signal-to-noise ratio, the required integration time for passive integrators is of the order of mag-

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[1] "Recent developments in color synchronization in the RCA color television system," RCA Labs. Report, Princeton, N. J.; Feb., 1950.

[2] Fig. 1 of "Minutes of the Meeting of Panel 14," NTSC; May 20, 1952.

[3] D. L. MacAdam, "Quality of color reproduction," Proc. I.R.E., vol. 39, pp. 468–485; May, 1951.

nitude of 0.005 second, or less than a sixth of a frame period. Locked integrators on the same assumptions require 0.01 second for the integration to take place.

(c) The third requirement, of pull-in or stabilization time, is also limited by the signal-to-noise ratio and the requirement for integration. This may vary considerably with the method of instrumentation, but the limiting or optimum performance with regard to stabilization time is determined by the information carried in the signal; the limit imposed by signal information is found to be (for a reasonable measure of reliability) a few times the integration time discussed above. Later in this report this is shown to be approached under certain conditions by fairly simple passive integrators. It is also shown how locked integrators, characterized by some new forms of automatic frequency- and phase-control loops, may be made to achieve the upper limit of performance. Typical present APC (automatic phase control) circuits fall somewhat short of this limit, but when properly designed can be made to pull in quickly enough so as to appear virtually instantaneous, while permitting most of the burden of frequency stability to be borne by the transmitter.

These facts lead to the conclusion that there is adequate information in the color burst for completely automatic operation, without need for a customer control. The factors leading to this conclusion are presented in the following sequence:

Performance limitations for sync systems which are already synchronized are discussed first, in the section on "Synchronization Accuracy." The reliability of phase difference measurements, and factors relating to the integration time necessary to obtain a specified measure of reliability in the presence of noise are considered.

Then performance limitations of instrumentation systems are discussed with particular regard to the process of synchronization. The basic characteristics of passive and locked integrators are discussed in the section on "Elemental Sync Systems."

Evaluation of ultimate limitations for the signal, and factors leading to new sync systems capable of fully utilizing the signal information are presented in the section on "Theory of Synchronization." Factors of interest are mechanisms of pull-in, the reliability of frequency difference measurements, and the exchange of integration time for a specified measure of reliability in the presence of noise.

Effects of echoes and stability of the gate are briefly discussed.

The conclusions drawn regarding the adequacy of the signal are stated.

Mathematical derivations, which substantiate and illustrate the facts presented in this paper, are presented in several appendexes.

The NTSC Color Synchronizing Signal

Fig. 1 shows the NTSC color synchronizing signal in relation to the video and synchronizing wave form, in the vicinity of one line-retrace interval. It consists of a burst of approximately 9 cycles of sinusoidal wave form at the color-carrier frequency of 3,579,545 ($\pm$.0003%) cps,[4] approximately centered on the portion of the line blanking pulse following each horizontal sync pulse. It is omitted during the nine lines in each field in which the field synchronizing information is transmitted.

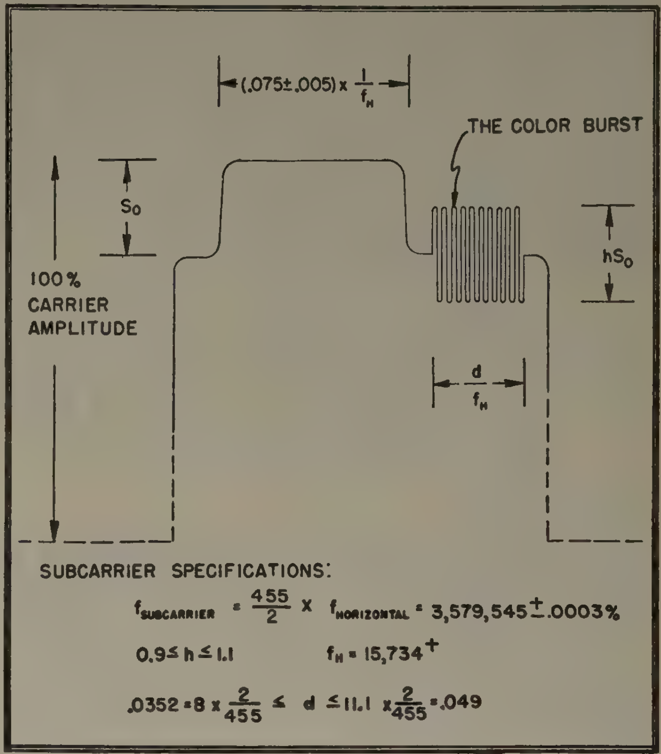

Fig. 1—Wave form during line retrace interval showing horizontal sync pulse and the NTSC burst reference signal.

Parameters of interest which are shown on the figure are:

S_0 = the amplitude of the line and field sync pulses, normally 25% of peak carrier amplitude measured in the video signal.

hS_0 = the peak-to-peak amplitude of the burst, measured in the video signal.

f_H = the line scanning frequency.

d = the duty cycle of the burst.

The color burst is used in the color television receiver to provide a control signal for the generation of a local continuous wave signal at the nominal burst frequency and locked to it in phase.

Synchronization Accuracy

Synchronizing Information

Any time-varying signal can carry timing information, the character of which depends on the distribution of signal energy throughout the frequency spectrum. In

[4] As specified by NTSC in February, 1953. The analysis is not critically dependent on the exact value of the color carrier frequency.

the case of a continuous sine wave, this timing information consists only of phase reference information because it is impossible to identify cycles of the carrier from each other. The same is essentially true of the pulse modulated sine wave which constitutes the burst; envelope information in the burst is not used. It is this phase reference information which is of interest with regard to color-carrier reference phase synchronization.

A signal which passes only through linear noiseless channels may be located in time (or phase) with theoretically unlimited precision. In the presence of noise the data obtained by a time (or *phase*) meter from the signal will fluctuate. This occurs because the timing information which can be extracted from the combination of signal-plus-noise in any specified interval is limited by the signal-to-noise ratio as well as by the statistical characteristics of the signal and noise.

Integration for Signal-to-Noise Ratio Improvement

The fluctuations in the phase data may be smoothed by integration. For example, the instantaneous output of the phase meter may represent the average of all data obtained over some preceding integration period T_M in duration.

Any measuring device which uses any form of integration or memory averages some effective number of independent measurements. One such integrator directly obtains a suitably weighted average (such as the least square error average) of all the data obtained in the preceding period T_M. Such an integrator provides a standard of comparison. Other forms of integrators may then be characterized by their effective integration times, T_M; several practical integrators are described later.

A section of a signal existing in an interval of duration T_M may be expressed as a sum of harmonics of the fundamental frequency $(1/T_M)$; the noise bandwidth associated with each component is equal to the spacing between components, or $1/T_M=f_N$. This means, for example, that if all of the timing information obtained in a period T_M from a signal consisting effectively of a signal sinusoidal component is averaged, that an improvement in reliability is obtained equivalent to that produced by passing the signal through a filter having a noise bandwidth of f_N.

Noise Interference

Noise is specified by its energy content and statistical characteristics. For a flat energy spectrum, taken as an example, impulse noise and white thermal noise represent opposite extremes, since for white thermal noise the relative phases of the several frequency components are completely random and incoherent; for impulse noise the relative phases of all components are related and are not random, although the time of occurrence of any impulse is a random variable.

Noise may be measured in terms of any convenient co-ordinate system into which the signal-plus-noise may be transformed, such as frequency, phase, amplitude, time of arrival, or more complex parameters.

Thermal noise is the most difficult to reject. It may be discriminated against only by averaging; this makes the effective error due to noise vary inversely as the square root of the number of measurements; hence, (for systems with fixed bandwidth) the error varies inversely as the square root of the integration time.

Impulse noise, or noise intermediate between thermal and impulse noise, may be rejected more easily than thermal noise since it represents a signal which can be recognized with a high measure of reliability and removed from the transmission channel.

A synchronizing system is a form of predictor which bases its estimates on past experience. When the input to the system has such a character (such as an improbable amplitude) that it is recognized with high reliability to be a disturbance, it is usually much better to use (at least approximately) the predicted signal as the input to the system for the duration of the disturbance. An equipment system for performing these operations is called an *aperture*. (Aperture systems are now widely used for line and field sync; the same principles are involved in the application to burst sync.)

Since thermal noise represents the most serious (as well as perhaps the most common) limitation to color synchronization performance, it is used in this paper as the measure of interference which must be overcome.

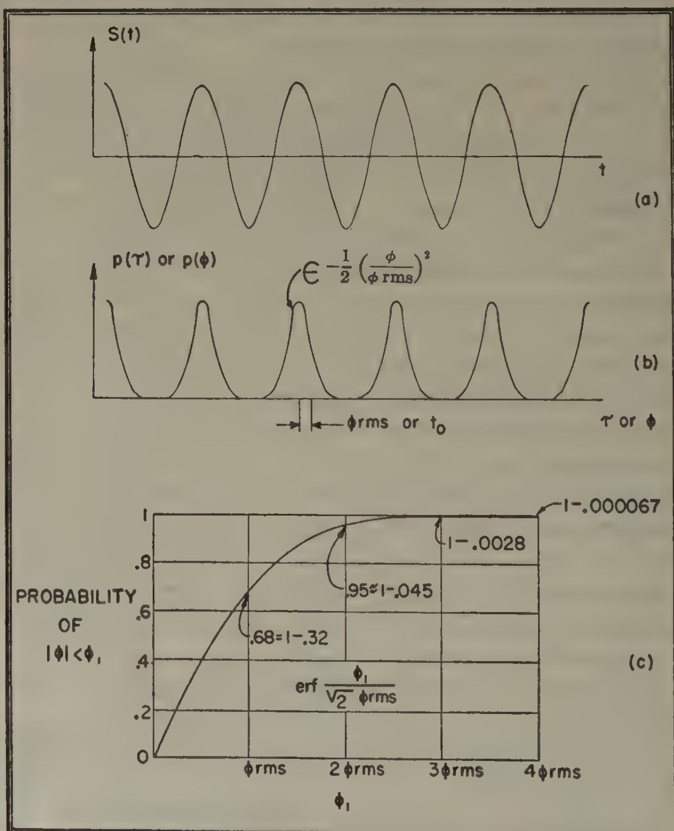

Fig. 2—Timing error distribution.

Measures of Reliability

A section of the burst reference signal is represented as $S(t)$ in Fig. 2(a). The time scale associated with the synchronizing signal may be identified with some representative point in a cycle which is selected as a reference.

The timing accuracy which is obtained for a given signal-to-noise ratio may be expressed in terms of a relative probability density function $p(\tau)$ such as is plotted in the curve of Fig. 2(b). The relative probability density curve permits the determination of the probability that the sync timing answer which results from a single measurement of the sync signal, using all of the information derived from the preceding period T_M, will occur within a specified time or phase interval. This probability is proportional to the area under the curve $p(\tau)$ or $p(\phi)$ within the specified interval. Due to the cyclic nature of the information, the time scale may be replaced by a phase scale. The curve for $p(\phi)$ defines the probability laws for the noise at the output of the synchronizing system. The curve is repetitive at the sync frequency. (The output noise from the sync measuring device has the same basic character from cycle to cycle.) For many signal energy distributions, and particularly for burst synchronization at the levels of output noise which give satisfactory performance, the curve $p(\tau)$ or $p(\phi)$ has very nearly the shape of a normal or Gaussian probability curve represented by the expression

$$\epsilon^{-1/2(t/t_0)^2} \quad \text{or} \quad \epsilon^{-1/2(\phi/\phi_{\text{rms}})}$$

in which case the phasing information may be completely described by the rms time error, t_0, or the rms phase error ϕ_{rms}, which may be expected for a specified set of measurement conditions.

For this case of the normal law the absolute probability that any measurement will yield an answer within a specified measure of the true answer may be represented in terms of the rms error. Fig. 2(c), which represents the integral of one lobe of the curve of Fig. 2(b) for the normal law, represents the probability that the magnitude of the phase error at any time is less than some selected phase error ϕ_1. ϕ_1 is measured in multiples of ϕ_{rms}. The curve illustrates that the probability is nearly unity only when ϕ_1 approaches $4\phi_{\text{rms}}$, which means that the effective peak value of Gaussian noise is near four times the rms value.[5]

The Sync Accuracy Equation

The parameters which determine the rms time error, t_0 seconds, for burst sync are:

The signal amplitude $\frac{1}{2}hS_0$ volts.

The duty cycle of the gated sine wave d as a fraction.

The rms noise (assumed flat over the band) N_W volts.

The video bandwidth occupied by the signal and noise f_W cycles per second.

The subcarrier frequency f_{SC} cycles per second.

The effective integration time T_M seconds.

The rms phase error ϕ_{rms} in degrees.

Equation (1) relates these parameters

$$\frac{S_0}{N_W} = \frac{1}{\sqrt{df_W T_M}} \frac{1}{t_0 f_{SC}} \frac{1}{\pi h} = \frac{1}{\sqrt{df_W T_M}} \frac{360}{\phi_{\text{rms}}} \frac{1}{\pi h}. \tag{1}$$

This equation is derived in Appendix A.[6] The physical significance of the several factors in (1) is as follows:

The factor S_0/N_W represents (for example) the smallest ratio of line sync amplitude to rms noise for which $t_0 f_{SC}$ will not exceed a selected arbitrary value. It may be visually estimated if the composite video signal is viewed with a wide band oscilloscope. When $S_0/N_W = 1$ the rms noise is equal to sync pulse amplitude. Since S_0 represents 25% carrier amplitude, and since the effective peak value of Gaussian noise is approximately four times the rms value, the condition $S_0/N_W = 1$ also corresponds to the "peak" noise being approximately equal to 100% of carrier amplitude.

The factor $t_0 f_{SC}$ represents the fraction of a cycle of phasing error at frequency f_{SC} corresponding to the timing error, t_0. Thus

$$t_0 f_{SC} = \frac{\text{rms phase error in degrees}}{360°} = \frac{\phi_{\text{rms}}}{360°}.$$

The factor $df_W T_M$ is the number of effectively independent measurements yielding phase information which may be made in the interval T_M on a signal which is present for only a fraction d of time, and which occupies portions of the bandwidth f_W. The signal is actually present for a period dT_M; the effect of integrating over the period T_M is therefore to reduce the rms error by

$$\sqrt{df_W T_M} = \sqrt{d \frac{f_W}{f_N}},$$

where $f_N = 1/T_M$ is the effective noise bandwidth.

The factor $1/\pi h$ is a constant.

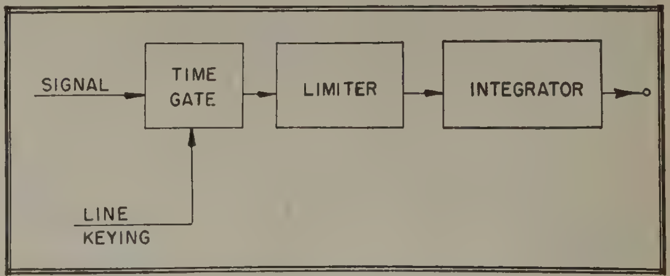

Fig. 3—Typical color-carrier phase reference generation system.

The Required Sync Accuracy

Equation (1) represents the theoretical upper limit of the phasing accuracy which may be derived from the subcarrier burst. A variety of circuits are available which can approach closely to this limit; these circuits are often of the form shown in Fig. 3. The composite

[5] V. D. Landon, "The distribution of amplitude with time in fluctuation noise," Proc. I.R.E., vol. 29, pp. 50–55; Feb., 1941.

[6] D. Richman, "Theoretical limit to time difference measurements," *Proc. NEC*, vol. 5; pp. 203–210; 1949.

video signal is fed to a time-gate which is keyed from line flyback to select the burst, which is then amplitude limited and integrated. Practical integrators are described later.

The sync accuracy equation permits the determination of how much integration is required in order to obtain satisfactory performance under extreme conditions. However, due to the many subjective factors involved it is not possible to specify exactly what is the lowest level of signal-to-noise ratio which will be tolerable from a visual viewpoint;[7] it is equally difficult to specify exactly the largest value of rms phasing error which will not cause visible degradation of the picture. Accordingly, Fig. 4, which is a plot of (1), presents graphically the relations between the relevant factors over a range which probably includes the limiting case of interest. Fig. 4 is based on adverse tolerances presented below.

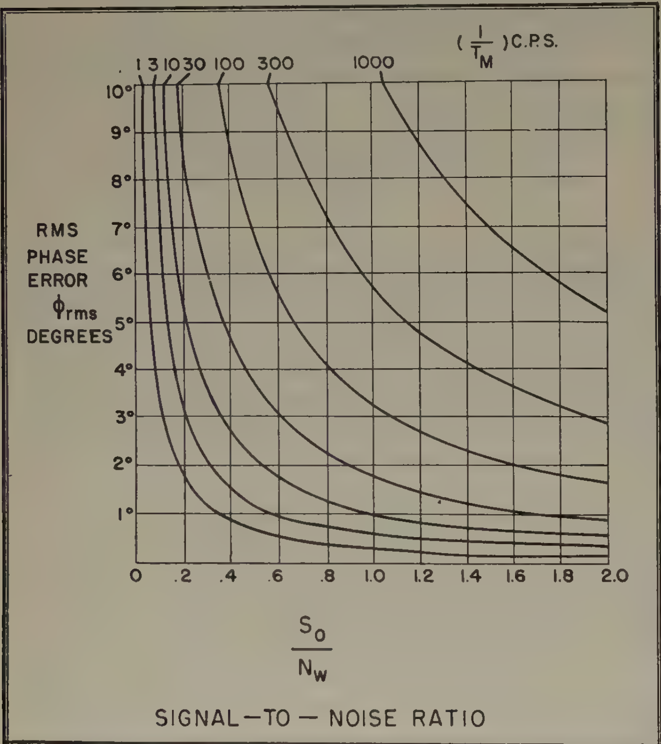

Fig. 4—Phasing accuracy relations for NTSC burst synchronization.

Fig. 4 presents the relation between the rms phase error, ϕ_{rms}, (in degrees) and the signal-to-noise ratio, S_0/N_W, with the integration time, T_M, (in seconds) as a parameter.

For the case corresponding to the most adverse tolerances, $h=.9$, $d=.0352$, and $f_W=4.3$ mc. Equation (1) then reduces to

$$\phi_{\text{rms}} \frac{S_0}{N_W} = .33\sqrt{\frac{1}{T_M}} = \frac{1}{3}\sqrt{\frac{1}{T_M}} \tag{2}$$

which is shown graphically in Fig. 4.

[7] P. Mertz, A. D. Fowler and H. N. Christopher, "Quality rating of television images," PROC. I.R.E., vol. 38, pp. 1269–1283; Nov., 1950.

These curves show that any selected phase accuracy ϕ_{rms} can be obtained with decreasing signal-to-noise ratio S_0/N_W if more time T_M is taken for integration of the signal timing information; i.e., if more measurements are integrated in each complete measurement.

(The facts presented later in this paper with regard to the relations between noise integration and other properties of sync systems indicate that the conclusions reached regarding the reliability of the signal are *not* critically dependent upon the assumed values of S_0/N_W and ϕ_{rms}.)

System Efficiency and the Distribution of Timing Information

The relationships presented above describe the performance of the system when all of the information of the signal is applied usefully. Another parameter which needs to be introduced in order to determine the actual noise bandwidth required is the decoding efficiency, which represents the fraction of the timing information of the signal which is used. Systems with equal noise bandwidths but different decoding efficiencies will give different performance.

In the burst system practical considerations relating to tolerances and to the stability of the gate derived from horizontal sync may result in a gate width r times wider than the narrowest sync burst. Factors relating to this are described later. It results in a requirement of noise bandwidth and integration time such that

$$T_M = \sqrt{r}\, T_{M\text{LIMIT}}$$

$$f_N = \frac{1}{\sqrt{r}} f_{N\text{LIMIT}}$$

where

$(1/\sqrt{r})$ is a system efficiency

r = ratio of actual gate width to minimum burst width.

There is another cause of loss of decoding efficiency in sync systems which is of interest. This relates to the relative distribution of timing information in the frequency spectrum. For burst sync systems which are properly designed, effectively all of the information may be used; (common attainment in horizontal sync systems has not been so high).

Fig. 5(a) shows the relative distribution of timing information in the frequency spectrum occupied by the burst. The basis for this curve is discussed in Appendix A. The effective accuracy which can be obtained if only a portion of the information is used may be measured in terms of the ratio of the noise bandwidth required (at any specified signal-to-noise ratio) to the noise bandwidth required if all of the information is used. For example, a problem of interest in receiver design is the relationship between bandwidth in the burst amplification channel and efficiency. If a passband symmetrically tuned about subcarrier frequency is used in this channel then the system efficiency resulting is represented by

the curve sketched in Fig. 5(b). The curve depends, of course, on the width of the burst. Even for the narrowest burst a total bandwidth of approximately 600 kc translates nearly all of the timing information.

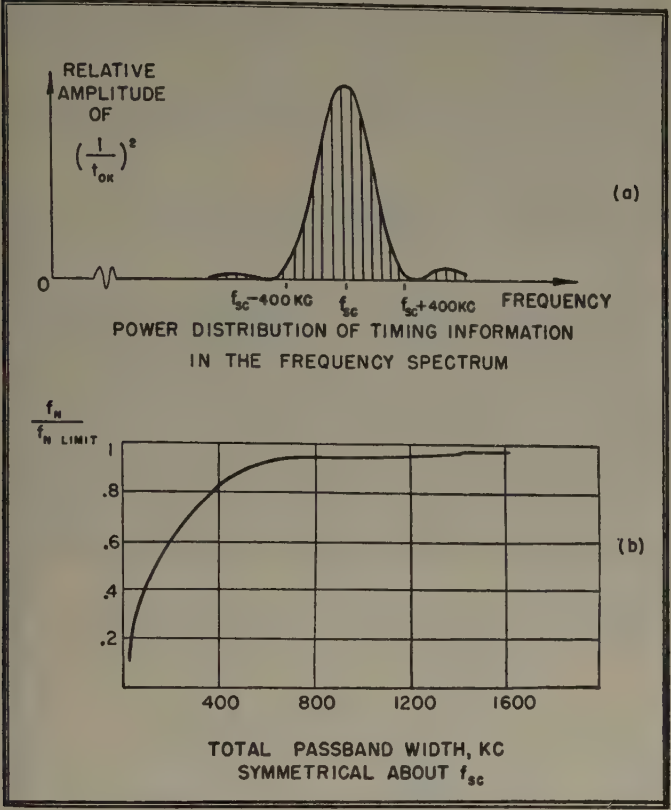

Fig. 5—Frequency distribution and system efficiency of burst sync timing information.

Example: As an illustration suppose the limiting parameter values of interest are approximately $\phi_{rms}=5°$ and $S_0/N_W=1$; these conditions correspond to the point in the center of Fig. 4; then from (2) $T_M \geq 0.0045$ second. *The required noise bandwidth* for a gate width ratio $r=1.2$ is then approximately $f_N=200$ cycles per second. *This figure is used as a basic design parameter for the practical forms of integrators which will be discussed in this paper.*

Elemental Sync Systems

The function of combining signal information derived over an extended interval of time is accomplished by use of circuits which may broadly be classified as integrators. The performance characteristics of two basic forms of integrators are discussed below. The parameters of interest are:

1. The noise bandwidth and integration time of the system.
2. The static phase accuracy. In general, in systems involving feedback, this varies inversely with a circuit gain parameter and may be made nominally as small as desired.
3. The frequency pull-in range of the system. This is the maximum (single peak) frequency detuning for which the system will automatically achieve the desired final operating condition.
4. The stabilization time T_S; or the time required for all operating characteristics to reach effectively their stabilized conditions. This may consist of one or more definable segments.
5. The phase pull-in time T_ϕ; or the transient time required for the output phase of the system to reach some definable measure of its final conditions.
6. The frequency pull-in time T_F, applicable to systems in which a local signal oscillator must be controlled, or the time necessary for the oscillator frequency to be changed from its initial frequency to some selected reference frequency such as a frequency from which the net differential phase change between sync signal and reference oscillator will not exceed one whole cycle. This overlaps the phase pull-in time T_ϕ.

The first integration system discussed is the Passive Integrator. For this system stabilization consists effectively of a phase transient. The limitations of this system are: practical limitations on how high the circuit Q may be and the possibility of detuning.

These limitations are overcome in the second form of integrator called a Standard APC (Automatic Phase Control) System. In this system the signal is heterodyned against a local carrier at the same frequency permitting the desired filtering to be accomplished by means of a low-pass filter which thus effectively provides unlimited Q. The limitations of this system relate to the difficulties of obtaining synchronization and the long pull-in times which result when narrow noise bandwidths are required.

The real limitations imposed by the signal, and some system fundamentals related to using all of the information in the signal, are presented later.

Passive Integrator

The circuit of Fig. 6(a) shows one form of practical integrator. This is a passive integrator in which the required integration is obtained by use of a high-Q filter. The input signal to the filter consists of time-gated amplitude-limited bursts of sine waves at subcarrier frequency f_{SC}. Because of the gating and limiting, sidebands near f_{SC} (which are separated by integral multiples of f_H) as well as harmonics of f_{SC} which are generated in the preceding limiter, all have effectively the same phase modulation due to noise. The noise bandwidth of the filter needs to be less than or equal to the value of f_N which was computed above. If the filter is approximately equivalent to a single resonant circuit, the noise bandwidth is $f_N=(\pi/2)f_3$ where f_3 is the 3 db bandwidth. The bandwidth f_N is indicated in Fig. 6(b). Thus the filter bandwidth should be approximately $(2/\pi)(200)=127$ cps between 3 db points. The Q desired is $f_{SC}/f_3 \approx 28{,}000$. This requires the use of a crystal filter. Practical crystals in the frequency range of the color subcarrier can achieve the required Q, but up to the present time apparently cannot exceed it by a

large factor.[8,9] The sum of transmitter frequency tolerance of ± 11 cps and the frequency tolerance of the crystal is comparable with the filter bandwidth. Fig. 6(c) shows how undesirably large static phase shift might result from normal detunings. This is prevented in the system shown in Fig. 6(a) by use of feedback for automatic

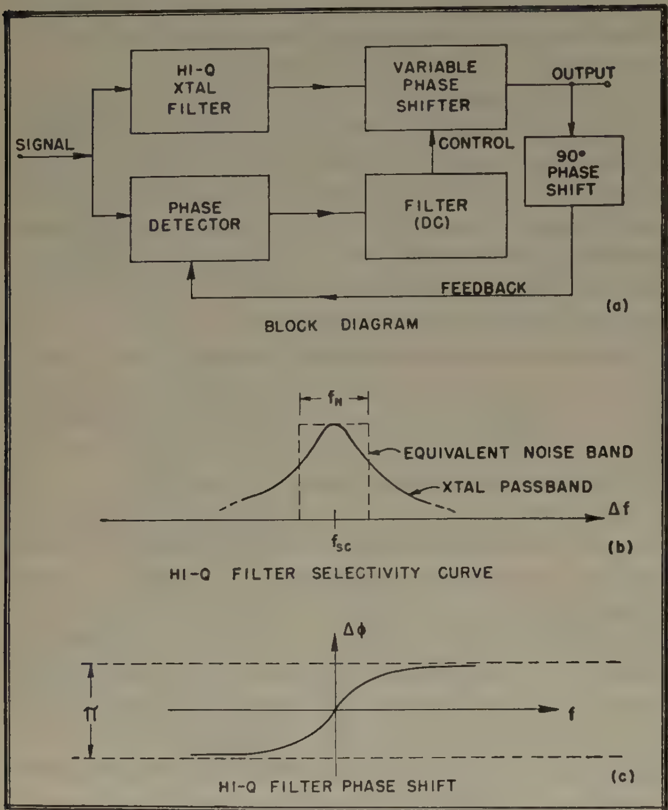

Fig. 6—Passive integrator.

static phase correction. The circuit includes in addition to the high-Q crystal filter a variable phase shifter, a phase detector (which has associated with it a 90° phase shift in one of the signal paths) and a low-pass (dc) filter in the feedback loop for correcting the average phase of the system. Other arrangements are possible; for example, a post-corrector might be used with the feedback signal derived directly from the output of the crystal filter, or a controllable reactance might be coupled to the crystal filter to insure optimum tuning.

The static phase may be maintained as closely accurate as desired by putting a suitably large amount of dc gain in the feedback loop. The signal-to-noise ratio at the output of the system will not be measurably changed if the dc filter is such that the bandwidth of the phase feedback loop is narrower than that of the crystal filter. Design considerations are discussed in Appendix B.

If the crystal stability is comparable to the transmitter frequency stability, the frequency error will be small enough so that rapid phase stabilization will occur when channels are switched. The switching transient is a phase transient and the stabilization time for small detunings will be or the order of a few times the transient time constant of the phase feedback loop. For the crystal bandwidth required, this time is essentially instantaneous. It may be noted however that if appreciable mistuning could occur the gain versus frequency characteristic of the high-Q filter would substantially reduce the amplitude of the correction signal, resulting in considerably increased stabilization time, and effectively reduced loop gain.

Standard Automatic Frequency and Phase Control Locked Integrator

Fig. 7(a) shows the block diagram of a standard automatic frequency and phase control loop. It includes a local reference oscillator, a phase detector which compares the relative phase difference between the sync signal and the oscillator, a filter which partly determines the transfer characteristic of the APC loop as an integrator, and a reactance tube for controlling the oscillator frequency. The loop gain for this system has the dimen-

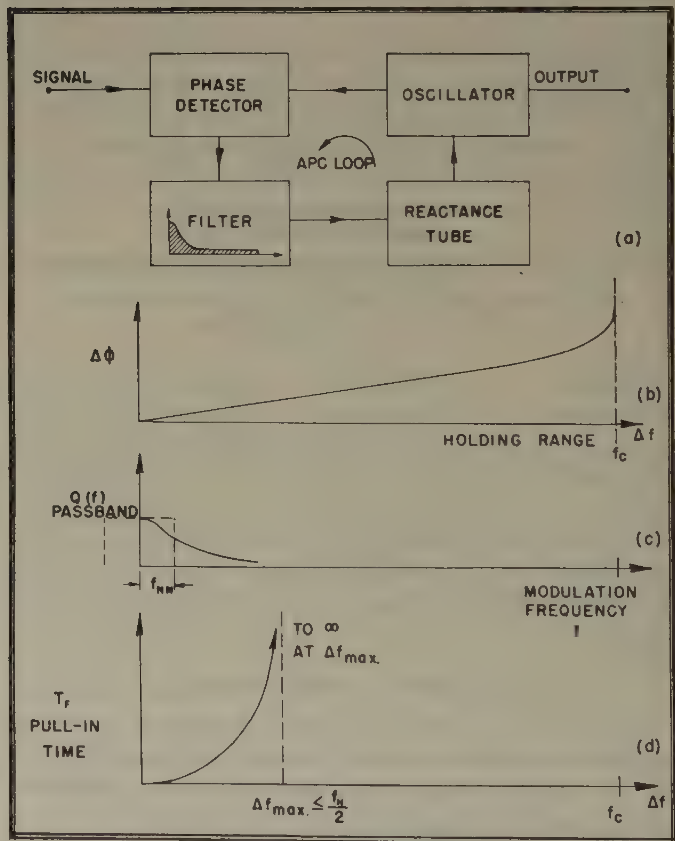

Fig. 7—Standard APC locked integrator.

sions of a frequency, f_C, which is equal to the frequency holding range of the APC system. Included in this characteristic is the dc transmission of the filter. Fig. 7(b) shows the relationship between the static phase error, $\Delta\phi$, and initial oscillator detuning, Δf. By making the holding range much larger than the normal operating range the static phase may be controlled as tightly as desired; here again the price of this control is high loop

[8] W. G. Cady, "Piezoelectricity," McGraw-Hill Book Co., Inc., New York, N. Y.; 1946.

[9] A. W. Warner, "High-frequency crystal units for primary frequency standards," Proc. I.R.E., vol. 40, pp. 1030–1033; Sept., 1952.

gain. Fig. 7(c) shows effective passband characteristic $Q(f)$ of the APC loop as a function of modulation frequency. This is determined largely by the ac transmission of the filter in conjunction with the feedback characteristics of the loop. The noise bandwidth f_{NN} is defined in the normal fashion and indicated on the figure. Since an APC loop phase detector is essentially a synchronous detector and does not distinguish between those noise components which are above or below the local oscillator frequency, then $f_{NN}=f_N/2$, and the effective integration time $T_M=1/2f_{NN}$; the noise bandwidth of the APC loop should not exceed approximately 100 cps for equivalent performance with the high-Q filter.

Fig. 7(d) is a sketch of pull-in time for this loop as a function of Δf. The pull-in range cannot exceed half the gating frequency, i.e. $f_H/2$, and for many designs is substantially smaller. The pull-in mechanism of this loop is not the most efficient one possible. Pull-in times are particularly long near the limit of the pull-in range. The APC loop of Fig. 7(a) is of the same basic type[10] which has achieved essentially universal use in television receivers as an integrator for line frequency synchronizing information. A detailed analysis of the characteristics of this loop is presented in Appendix C and a derivation of the pull-in time relationships is presented in Appendix D.

The pull-in range and time are a function of some design parameters discussed later. It has been found that for optimum design there is a limit to the pull-in performance obtainable with this loop. For these limit designs the following performance is obtained:

(a) The static phase error $\Delta\phi$ may be as small as possible and in fact must be smaller than some specified number in order that pull-in time be minimized.
(b) The pull-in range is equal to $\pm(f_H/2)$.
(c) Except near the limit of pull-in range, the pull-in time and noise bandwidth are very nearly related to the frequency detuning, Δf, by (3)

$$T_F f_{NN} \approx 4\left(\frac{\Delta f}{f_{NN}}\right)^2. \tag{3}$$

This has been used in Fig. 8 to plot the limit of pull-in performance for optimum design standard APC loops. Fig. 8 represents the pull-in time T_F in seconds as a function of the noise bandwidth f_{NN} in cycles per second. The range of f_{NN} in this log-log plot is from 10 to 1,000 cps with the approximate normal required bandwidth of 100 cps in the center of the graph. Pull-in times ranging from less than one-tenth to approximately one second appear instantaneous and may be characterized as "good." Pull-in times between 1 and 10 seconds are acceptable but probably close to the limit of adequate performance and have been designated "fair." Pull-in times in excess of 10 seconds are definitely "poor."

The relationship between f_{NN} and T_F is shown for several values of Δf. For example an optimum design unit having a noise bandwidth of 100 cycles will require 4 seconds to pull in from 1,000 cycles detuning. This indicates that such a sync system should be adequate for completely automatic phase control but that it apparently does not have an excess of available performance; for example, if the noise bandwidth needed to be reduced to 50 cycles, then 32 seconds would be required to pull in 1 kc.

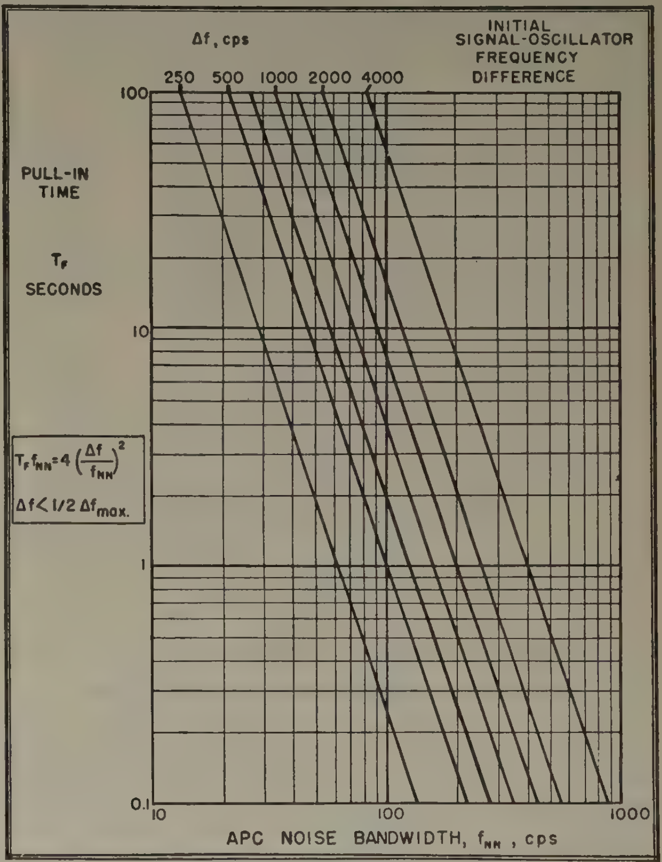

Fig. 8—Standard APC optimum pull-in performance.

Pull-In Performance Attainable with a Standard APC System

Not all designs of APC circuits will achieve the limits of performance discussed with respect to Fig. 8. In fact, partly due to economic limitations, the majority of past designs have fallen short of the limit. Accordingly, Figs. 9 and 10 are presented as a basis for demonstrating the pull-in limitations of the Standard APC System. The curves are expressed in terms of what are believed to be the parameters of interest to the user, specifically the noise bandwidth f_{NN}, the initial frequency difference Δf, and the frequency stabilization time T_F. The dimensionless parameters $T_F f_{NN}$, and $\Delta f/f_{NN}$, are used as ordinate

[10] K. R. Wendt and G. L. Fredendall, "Automatic frequency and phase control of synchronization in television receivers," Proc. I.R.E., vol. 31, pp. 7–15; Jan., 1943.

and abscissa. Two different parameters, designated m and K, which are discussed in Appendix C, appear. The parameter m varies inversely as the dc loop gain for fixed noise bandwidth. The figure shows that increased dc loop gain (smaller m) and hence tighter static phase control permit wider pull-in range and a closer approximation to the minimum pull-in time curve. The parameter K which is a damping coefficient (discussed in Appendix C) determines the level of the limit curve as indicated in Fig. 10. Over part of its range of variation the parameter K permits an exchange of minimum pull-in time for pull-in range. The maximum increase, however, is limited to a 50% increase in frequency pull-in range, over designs which approach the optimum pull-in time limit curve.

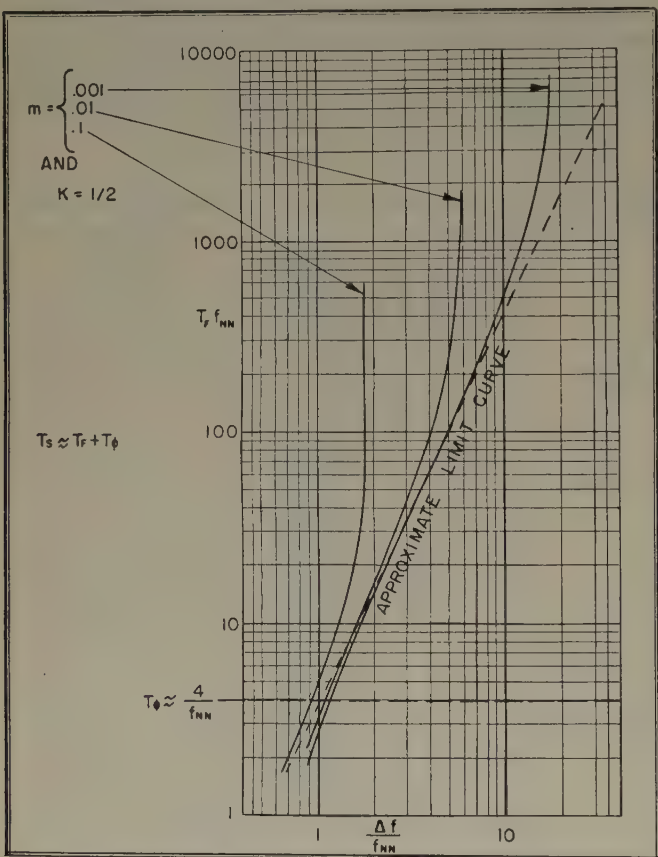

Fig. 9—Pull-in characteristics of standard APC loop.

The mathematics upon which these curves are based is presented in Appendexes C and D. Appendix C introduces and presents the relevant relations between the parameters of the Standard APC System. Derivation of the pull-in time equation and discussion of the pull-in phenomenon is presented in Appendix D.

Theory of Synchronization

Improved Sync Systems

The systems described thus far permit a level of performance which appears to satisfactorily meet the requirements for burst synchronization but do not appear to have a large excess of performance. The signal itself permits substantially better performance.[11] This will be shown below by considering the limitations of the systems presented thus far and introducing the factors which lead to full utilization of the signal information. This leads to a sync system which appears capable of efficiently using all of the timing and synchronizing information in the signal. Then an implementation of this system is described which appears applicable to NTSC color television receivers to produce what may be ideal performance at no substantial cost increase.

Finally, the approximate upper limit of performance capability for the signal is evaluated numerically. The limitations on the previous system relate to the severe restrictions interrelating noise bandwidth and pull-in time. There appear to be a variety of new sync systems which can overcome this limitation. Several varieties have been instrumented and found practical. However, the potentialities of the NTSC burst sync system are perhaps most clearly demonstrated by examining what may be the upper limit of performance.

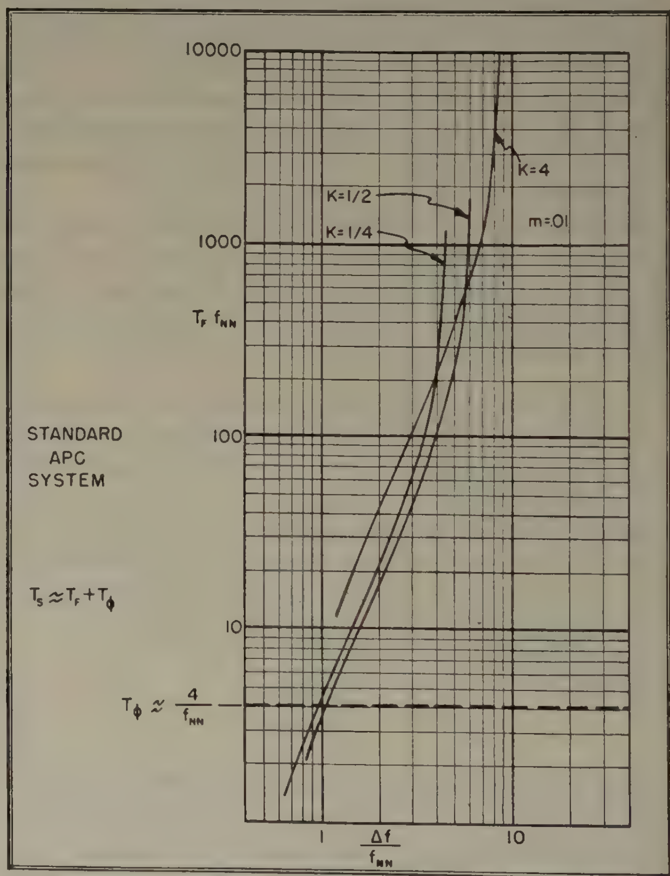

Fig. 10—Effect of variations in the parameter K.

Two Mode Systems

There are two separate and distinct modes of performance of sync systems. These relate to (a) the phase stability attainable after the system has achieved a stable synchronized operating condition, which has been

[11] D. Richman, "Theory of synchronization applied to NTSC color television," IRE Convention Record, Part 4; 1953.

discussed in some detail earlier in this paper, and (b) the performance associated with the system achieving that final state. Each of these modes has fundamental physical restrictions and characteristics associated with it. The full measure of performance permitted by the signal can be achieved by a system which makes these two modes of operation as independent as possible of each other and of each other's limitations.

Some systems use the same mechanism for hold-in and pull-in. The Standard APC System falls into this category. It is inefficient in its use of signal information. Other types of systems use a multiplicity of mechanisms, usually two.[12] One mechanism is designed for stable performance after synchronization, the second mechanism is designed to produce synchronization. *Such a device must have within it the inherent ability to extract from the signal the necessary information with regard to the mode of performance which is required.* For example, it should not confuse noise which may be present when the system is synchronized with a beatnote indicative of a lack of synchronism.

Factors Relating to Frequency Pull-In

There are two basic factors which relate to frequency pull-in. The first problem is concerned with the mechanism whereby a frequency difference is recognized in the presence of strong signals and a control voltage generated which can be utilized for pull-in. The second problem relates to the ability of the mechanism associated with pull-in to discriminate against noise interference.

Frequency Recognition

This separation of the requirements of the system leads to the following principle. *The real limitation of a synchronization system with respect to frequency pull-in is the ability of the system when out of sync to recognize a frequency difference and distinguish it from noise.*

This sets the *real upper limit of performance.* If the frequency determination is effectively linear, then after a time delay which permits the frequency difference to be measured to within a suitable measure of reliability, the reference oscillator may be switched instantaneously by the proper amount to insure synchronization. A system for accomplishing this may be called an *ideal sync system.* Just as with phase measurements this reliability is obtained by integrating the frequency difference information for an adequately long period of time. The shortest stabilization time consistent with reliable performance is therefore determined by the integration time necessary to measure a frequency difference with a suitable measure of reliability.

The Pull-In Control Effect

Fig. 11 represents the generated control effect for pull-in for two important synchronization systems. Fig. 11(a) relates to the frequency pull-in characteristic of a standard APC loop. The generated control voltage for pull-in is shown as a function of instantaneous applied frequency difference Δf. If the frequency is within a range roughly two-thirds that of the noise bandwidth, pull-in (as explained in Appendix D) is effectively instantaneous. The system never slips a cycle; a dc voltage for frequency control is generated which is proportional to the frequency difference. For larger values of Δf the

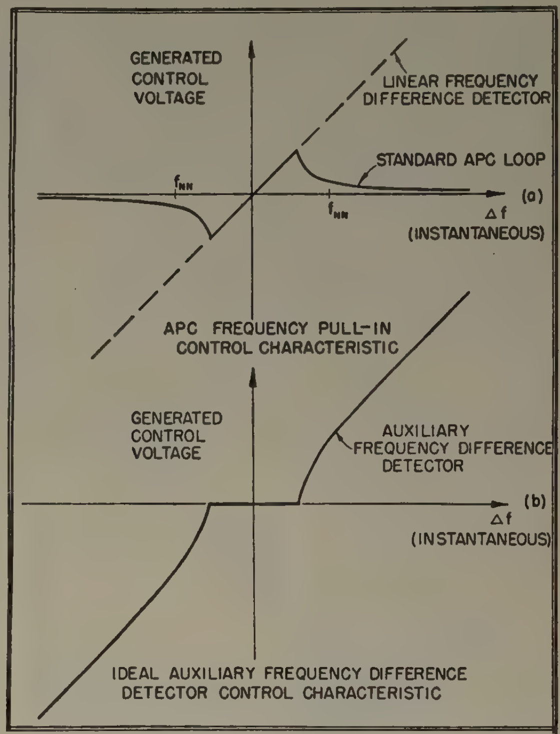

Fig. 11—Synchronization control characteristics.

system slips cycles but by virtue of the feedback in the APC loop generates a dc component of control voltage which varies in the inverse fashion with frequency difference indicated in Fig. 11(a). This inefficient control effect may be compensated for in this system by very high ratios of dc to ac loop gain ($1 \gg m$) but at the expense of the long pull-in times indicated by Fig. 9 and 10. An automatic frequency control system[13] containing a linear frequency difference detector[14] which generates a control voltage proportional to the frequency difference for all frequency differences of interest as indicated in Fig. 11(a) provides a more efficient indication of large frequency differences.

Improved performance may be achieved by supplementing the APC system with an "Ideal Auxiliary Frequency Difference Detector," the control characteristic of which is shown in Fig. 11(b). Such an auxiliary detector can provide a suitable control effect for nearly optimum pull-in performance and as indicated by the flat

[12] Fundamentals relating to systems analyzed here have been applied to automatic gain control circuits as well as to sync systems.

[13] C. Travis, "Automatic frequency control," Proc. I.R.E., vol. 23, pp. 1125–1141; Oct., 1935.

[14] C. F. Shaeffer, "The zero-beat method of frequency discrimination," Proc. I.R.E., vol. 30, pp. 365–367; Aug., 1942.

portion of the curve will *automatically turn itself off when synchronization has been achieved;* this occurs when the frequency difference is reduced to within the linear sloping portion of the curve of Fig. 11(a), within which range the standard APC loop can produce effectively instantaneous pull-in.

A Sync System which Efficiently Uses the Signal Information

Fig. 12 represents the block diagram for a sync system having the auxiliary frequency detection control characteristic described with regard to Fig. 11(b). It includes a Standard APC System such as was shown earlier in Fig. 7 and in addition an auxiliary frequency difference detector which supplements the pull-in performance of the APC system.

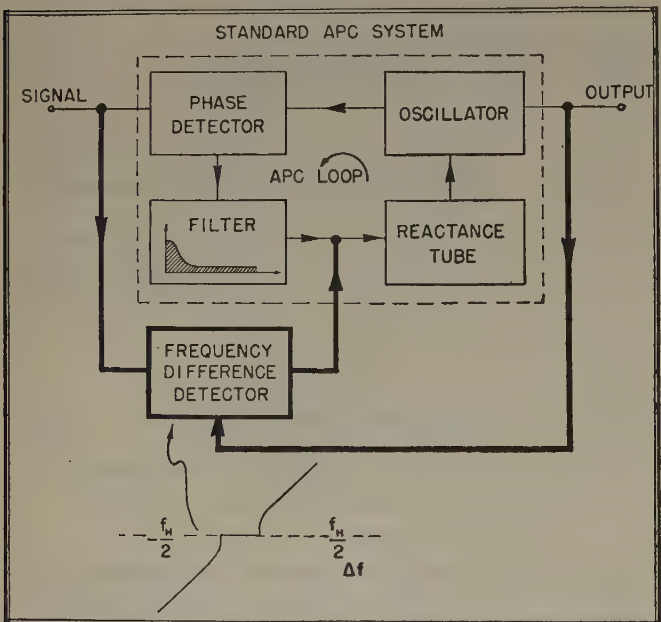

Fig. 12—A synchronization system capable of using total signal information at maximum efficiency.

The idealized upper limit performance described earlier under "Frequency Recognition" may be achieved by means of a suitable interconnection circuit. However, with the stepped characteristic of Fig. 11(b) an essentially direct connection is feasible. The composite system functions as a form of automatic frequency control system when out of sync and as an automatic phase control system when in sync; the auxiliary frequency difference detector turns itself off automatically by virtue of the shape of its control characteristic.

The ideal switched system has pull-in time equal for all frequency differences.

AFC systems normally require high loop gain and are characterized by a pull-in time constant. In some instrumentations of the system of Fig. 12 a loop gain of approximately unity (or a little more for tolerance purposes) may be adequate if the frequency difference detector includes a small amount of delay in its output. As soon as the oscillator is brought near the frequency of the sync signal, the high-gain APC system becomes operative, and the frequency difference detector is automatically inactivated.

The Quadricorrelator: A Frequency Difference Detector

In order to illustrate in more detail the problems and characteristics associated with the achievement of effectively upper limit performance, a form of circuit arrangement is introduced here which appears capable of using elements already present in color television receivers operable on NTSC standards to achieve the ideal frequency difference detection described above. This form of circuit will be called a quadricorrelator in this paper. Analysis of the performance characteristics of the quadricorrelator presented in Appendix E shows that when preceded by a limiter it comes within a few db in signal-to-noise ratio of using all of the signal information for signal-to-noise ratios of interest here. When the limiter is omitted from the system, the quadricorrelator is an efficient frequency detector; the extra noise due to amplitude modulation disappears after pull-in.[15] It is a true frequency difference detector since it is not subject to tuning errors. The excess of available over required noise discrimination suggests that the limiter can be omitted.

There is no real purpose to accomplishing pull-in much more rapidly than perhaps a few tenths of a second. The simple quadricorrelator instrumentations appear (on this basis) to give effectively optimum performance.

A block diagram of a basic form of a quadricorrelator is shown in Fig. 13. Its elements are a pair of synchronous detectors which are fed with reference signals in quadrature with each other so that the phase detector outputs represent "in phase" and "quadrature" components of the applied sync signal. These output signals are then limited in maximum frequency to (for example) $f_H/2$ by filters as indicated in Fig. 13(a). The output of one of the synchronous detectors goes through a differentiating circuit which provides a 90° phase shift through the passband. The two signals are then heterodyned in another synchronous detector, and the output is integrated in a narrow band filter; a low-pass filter is shown. This filter exchanges brevity of integration time for reliability of frequency measurement. The resulting output signal is proportional to the frequency difference (as explained below) and is applied through an interconnection circuit to the controlled oscillator of the APC system of the receiver.

The mechanism by which the frequency difference is determined may be explained as follows: Assume that a frequency difference Δf exists between the sync signal and the local reference oscillator. The input noise may

[15] J. G. Chaffee, "The application of negative feedback to frequency modulation systems," Proc. I.R.E., vol. 27, pp. 317–331; May, 1939.

be considered for simplicity as the sum of two noise-modulated signals in quadrature with each other at the *oscillator* frequency. The output from one synchronous detector will contain a sine beatnote (see Fig. 13(b)) and the noise along one reference axis. The output of the other synchronous detector will contain a cosine beatnote (see Fig. 13(c)) and the noise along an axis in quadrature with the first reference axis. These two *noise* voltages are completely independent of each other.

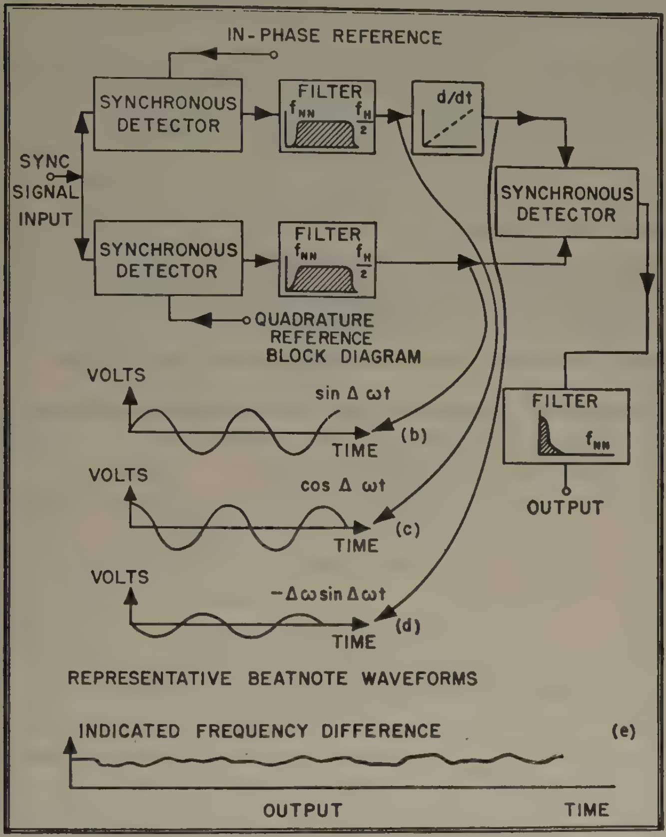

Fig. 13—Basic quadricorrelator.

The cosine beatnote is converted by differentiation to a sine beatnote having an amplitude which is proportional to its frequency, as indicated in Fig. 13(d); its associated noise is differentiated but the two noise voltages are still independent of each other. The output of the cross-multiplying synchronous detector will contain *a dc term proportional to and polarized according to the frequency difference*. In addition the output contains random noise; this noise output is discussed in Appendix E.

The quadricorrelator provides a convenient means for measuring a frequency difference with any selected measure of reliability in the presence of noise by integration of the frequency difference information.

An Illustrative Receiver Operable on NTSC Standards

Fig. 14 shows a partial block diagram of an NTSC color television receiver which includes color difference synchronous detectors, a Standard APC System, and a quadricorrelator for frequency difference detection. The composite video signal is fed to a pair of synchronous detectors for deriving the color difference video signal. The $R-Y$ synchronous detector output may be fed through an amplifier gated during line retrace to a filter, a reactance tube, and an oscillator, the output of which is fed back in the normal fashion to both synchronous detectors. These elements comprise a Standard APC System as described earlier. The gated outputs of both synchronous detectors are fed to a pair of filters as indicated. These may be bandpass filters having low-frequency cutoffs near the noise bandwidth of the APC system and having high frequency cutoffs not higher than half line frequency, as shown in Fig. 14. The differentiating circuit may be included in either beatnote translation path. The third synchronous detector and filter as indicated complete the elements of the quadricorrelator, the output of which is fed to the reactance tube. *The low-frequency attenuation characteristics of the filters in the two channels make the quadricorrelator have an essentially zero transmission characteristic for small beatnote frequency differences.*

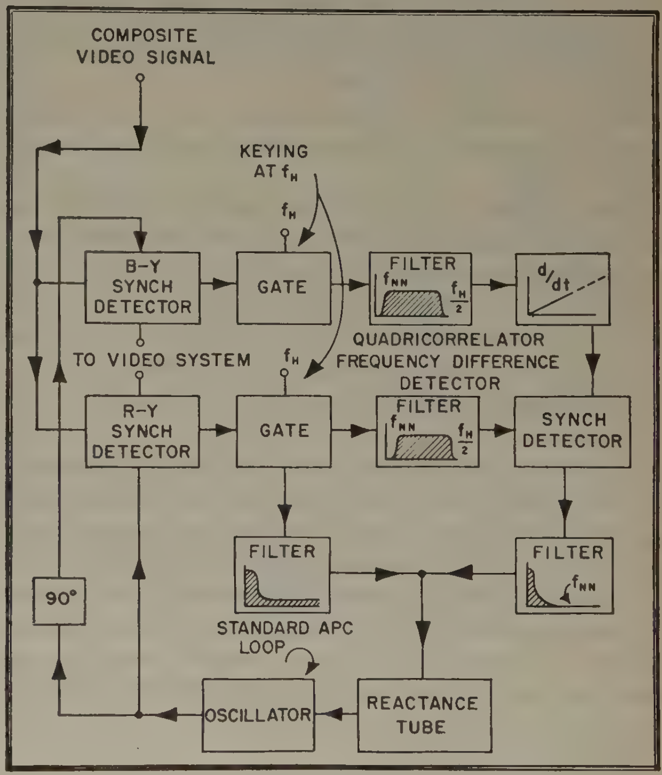

Fig. 14—Application of Fig. 12 sync system to NTSC color television receiver.

The circuit arrangement presented in block form in Fig. 14 provides one means for realizing the sync system of Fig. 12. Since this composite frequency- and phase-control system is essentially free of the previous limitations between noise bandwidth and pull-in time, the over-all system can be more readily designed for desired performance.

There appears to be a variety of frequency difference detector circuits and of linear and nonlinear interconnection

arrangements which can be used to approach upper limit performance in the burst system.

The excess of performance inherent to these arrangements appears exchangeable for receiver economy and long term reliability.

The Approximate Limit of Performance Permitted by Signal Information

There are three requirements on the sync system.

(1) The static phase error shall not exceed some selected value, say 5°. It is shown in Appendexes B and C that for both passive and locked integrators this may be accomplished by use of adequately high loop gain.

(2) The rms phase error shall not exceed some selected value, say 5°, for signal-to-noise ratios at least as high as the approximate lowest level for which monochrome video picture information is acceptable; this is approximately $S_0/N_W=1$.

The required noise bandwidth for the APC system is

$$f_{NN}=\frac{1}{2T_M}\approx\frac{1}{2}\left(3\phi_{\text{rms}}\frac{S_0}{N_W}\right)^2$$

from (2). (The effect of excess gate width is small and is neglected here for simplicity.)

(3) The stabilization time shall not be annoyingly long. For example, pull-in times shorter than 1 second are acceptable.

The minimum integration time required for frequency difference detection yielding an rms frequency error f_{rms} is shown in Appendix E to be

$$T_I=\sqrt{\frac{2}{d}}\,\frac{1}{\pi h}\,\frac{N_W}{S_0}\sqrt{\frac{f_H}{f_W}}\,\frac{1}{f_{\text{rms}}} \tag{4}$$

for the signal. This is based on a pull-in range of $\pm(f_H/2)$.

It is shown in Appendexes C and D that the linear portion of the curve of Fig. 11(a) extends to a value of Δf approaching $2f_{NN}/\pi$; the control effect is strong to near f_{NN}. Then, if for frequency differences between approximately $(2/\pi)f_{NN}$ and $f_H/2$, the error in frequency difference measurement is less than $(2/\pi)f_{NN}$, pull-in will occur in time T_I. The more severe of the following two requirements then determines the frequency pull-in time T_F.

$$T_I\geqq\frac{\pi}{2f_{NN}}\ \text{Approximately} \tag{5}$$

$$f_{\text{rms}}\leqq\frac{1}{4}\left(\frac{2}{\pi}f_{NN}\right)=\frac{f_{NN}}{2\pi}. \tag{6}$$

Combining (4) and (6),

$$T_I\geqq 2\sqrt{\frac{2}{d}}\,\frac{N_W}{S_0}\sqrt{\frac{f_H}{f_W}}\,\frac{1}{f_{NN}}\,\frac{1}{h}. \tag{7}$$

The same adverse tolerances used in obtaining (2) may be used here. If $d=.0352$, $h=.9$, $S_0/N_W=1$, $f_W=4.3$ mc, and $f_H=15734+$cps, then (7) becomes

$$T_I\geqq\frac{1}{f_{NN}}.$$

Thus, the required frequency pull-in time is of the order of magnitude of $1/f_{NN}$ or $(\pi/2)(1/f_{NN})$. After frequency pull-in, phase pull-in occurs. (Both occur effectively simultaneously in the continuous feedback system.) The time for phase pull-in is normally less than

$$T_\phi\approx\frac{4}{f_{NN}}. \tag{8}$$

The constant in (8) depends on the shape of the pass-band determining f_{NN}.

Then, the stabilization time, T_S is given by

$$T_S\approx T_F+T_\phi. \tag{9}$$

Since the required value of f_{NN} was found earlier to be 100 cps, pull-in times of the order of .05 second are possible. This is considerably shorter than is required, indicating that the information inherently contained in the signal is substantially in excess of what is required.

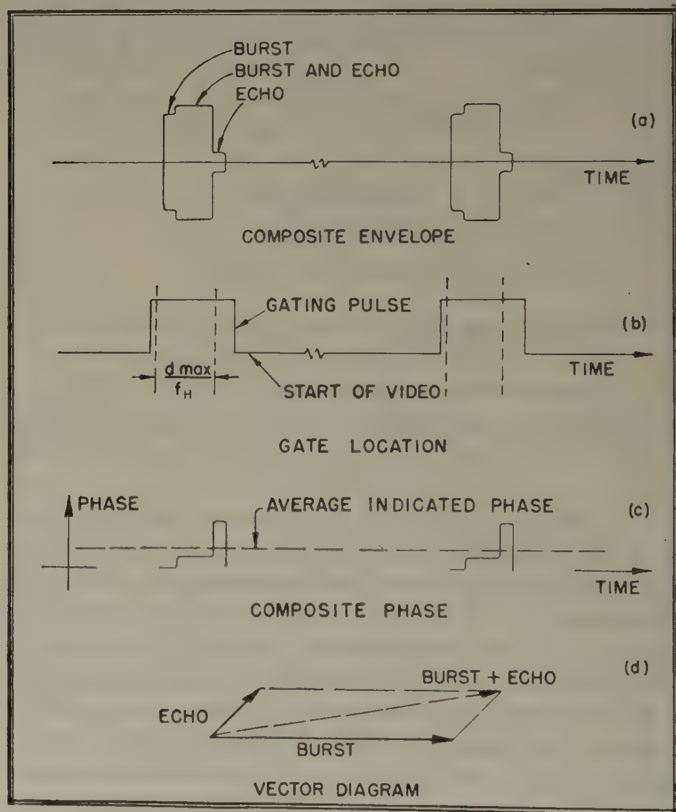

Fig. 15—Effect of echoes on the NTSC color burst.

Other Topics

Effects of Echoes

Some sketches relative to a discussion of the effect of echoes on burst sync are presented in Fig. 15. Fig. 15(a) shows one possible representation of a burst to which an echo has been added. Parameters of interest are the relative delay, the relative amplitude, and the relative phase. If the time-gate exceeds the burst width on the

lagging end as indicated in Fig. 15(b) combined signals may be used to operate the burst sync system. In this case the indicated phase as a function of time is as shown in Fig. 15(c) while Fig. 15(d) is a vector diagram representing the signals of interest. Phase angles of interest are indicated for the burst phase, for the phase of the sum of the burst and echo, and for the phase of the echo. The average phase is not necessarily equal to any one of these but may often be near the phase of burst plus echo. The phase of burst plus echo is the correct reference phase for low detail large area colors. For this reason it appears possible that some extra gate width as indicated in Fig. 15(b) may give a useful and efficient exchange of noise immunity for performance in the presence of echoes. However, the existence of high order correlation between widely separated picture elements[16] may be uncommon enough to make this effect relatively unimportant.

A complete discussion of the effect of echoes in the NTSC system is beyond the scope of the present paper.

Effect of Stability of the Gate

The gate is conveniently obtained from horizontal flyback. The effect of gate stability depends on two factors: the stability of the horizontal sync system which produces the gate; and the relative widths of the gating pulse and the burst, which determines the extent to which noise jitter of the gate can be cross-modulated into the burst channel.

The fundamental physical considerations which have been presented and discussed above with regard to burst synchronization are also true of horizontal synchronization although the shape of the spectral distribution for horizontal sync introduces some additional complications. The static phase may be controlled as closely as desired, limited ultimately by transmission tolerances. The stability may be held to any desired level still permitting effectively instantaneous pull-in.

The effect of cross-modulation when it occurs is to increase the noise power for those low-frequency components to which the horizontal sync system is responsive. The horizontal sync system appears to contain more information than it needs. Stability of the gate is a design consideration but it is not a real limitation of the burst sync system.

Conclusions

The discussion above has shown that standard sync systems appear capable of completely automatic synchronization for NTSC burst sync (although without a large *excess* of performance). In the presence of strong signals the burst sync system is capable of yielding a color-carrier reference having a reliability completely determined by the gain in the receiver sync system, while noise is rejected by integrating the timing information for a suitably long period. An *effective* integration time of the order of 1/200th of a second appears appropriate. Passive integrators using controlled crystal filters, appear capable of meeting the requirements on Q, frequency stability, and rapidity of stabilization. The Standard APC System, when designed for near limit performance, appears capable of providing adequate and usable performance. This means that for reasonable operating tolerances, synchronization will always occur, and with adequate synchronization accuracy.

Improved sync systems which overcome the ultimate limitations of the standard APC sync system have been presented along with a discussion of factors leading to improvement and of the upper limit of performance permitted by the signal. These indicate that the requirement of a high order of noise immunity does not limit synchronization performance in the manner and to the degree experience with previous circuits had indicated. A large excess of attainable as compared to apparently necessary performance appears to exist.

The NTSC color-carrier reference phase synchronization signal contains adequate information for reliable performance down to levels of signal-to-noise ratio where the signals are no longer usable in picture content. A variety of circuits can provide satisfactory performance.

Appendix A

Phase of a Sine Wave Plus Random Noise

Derivation of the Equation

The analysis of the theoretical limits to phasing accuracy may be based on the properties of a signal composed of a sine wave plus random noise.[17] The information of each frequency component may be determined separately and then all of the information may be combined.

The problem is solved here first for a continuous (ungated) sine wave.

The probability density distribution of amplitude coefficients for a sinusoidal signal plus two-dimensional Gaussian noise is shown in Fig. 16. The signal is

$$S(t) = S \cos \omega_{sc} t. \tag{A-1}$$

The noise may be written as

$$N(t) = a(t) \cos \omega_{sc} t + b(t) \sin \omega_{sc} t \tag{A-2}$$

where $a(t)$ and $b(t)$ are time-varying parameters, each having a Gaussian distribution, and defined by the mean square values shown below.

$$\overline{a^2} = \overline{b^2} = \overline{N^2}. \tag{A-3}$$

This equality results from the fact that by symmetry, $\overline{a^2} = \overline{b^2}$ while the total noise power

$$\overline{N^2} = \overline{(a \cos \omega_{sc} t + b \sin \omega_{sc} t)^2}$$

[16] E. R. Kretzmer, "Statistics of television signals," *Bell Sys. Tech. Jour.*, vol. 30, pp. 751–767; July, 1952.

[17] S. O. Rice, "Mathematical analysis of random noise," *Bell Sys. Tech. Jour.*, vol. 23, p. 282–332, July, 1944; vol. 24, pp. 46–156, Jan., 1945.

$$= \tfrac{1}{2}\overline{a^2} + \tfrac{1}{2}\overline{b^2}. \tag{A-4}$$

For the above case it is possible to express the probability distribution of phase angles for the combination of signal and noise, relative to the phase of the signal. This, however, leads to a cumbersome expression.[18]

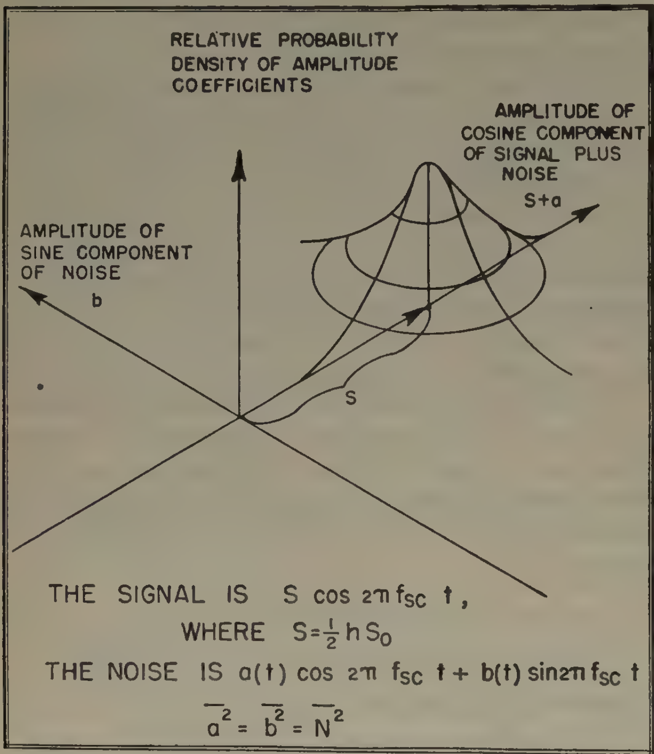

Fig. 16—Probability density distribution of a sine wave and random noise.

It is more convenient to use the simplified vector diagram shown in Fig. 17.[6] Here S represents the signal, and a and b represent the cosine and sine (in-phase and quadrature) components of noise.

Then if ϕ is the phase error,

$$\phi \approx \tan\phi = \frac{b}{S+a} \approx \frac{b}{S} \tag{A-5}$$

or, very nearly, since $b_{\text{rms}} = N$,

$$\phi_{\text{rms}} = \frac{N}{S}. \tag{A-6}$$

This equation is a good approximation if N/S is not large; in the case where the sync measuring system is primarily responsive to the noise in quadrature with a reference signal controlled by a long time constant of integration, it is accurate enough.

Then, since

$$N = \frac{N_W}{\sqrt{f_W T_M}} = \text{noise in the noise bandwidth} \tag{A-7}$$

$f_N = 1/T_M$, and since $S = \frac{1}{2}hS_0$, we obtain

$$\phi_{\text{rms}} = 2\pi f_{SC} t_0' = \frac{\dfrac{N_W}{\sqrt{f_W T_M}}}{\frac{1}{2}hS_0}. \tag{A-8}$$

The above equation applies for a continuous sine wave which is not gated. However, because the signal is present only a fraction d of the time, the integration is only $\sqrt{d}$ times as effective, and hence $t_0 = t_0'/\sqrt{d}$. Therefore, by substitution, the following upper limit relationship is obtained.

$$\frac{S_0}{N_W} = \frac{1}{\sqrt{d f_W T_M}} \cdot \frac{1}{f_{SC} t_0} \cdot \frac{1}{\pi h}. \tag{A-9}$$

This is (1), presented earlier.

If the signal plus noise is passed through a limiter, the output of the limiter is approximately

$$S \cos \omega_{SC} t + b(t) \sin \omega_{SC} t$$

for signal-to-noise ratios of interest. Thus, the limiter aids in achieving the upper limit, without improving it.

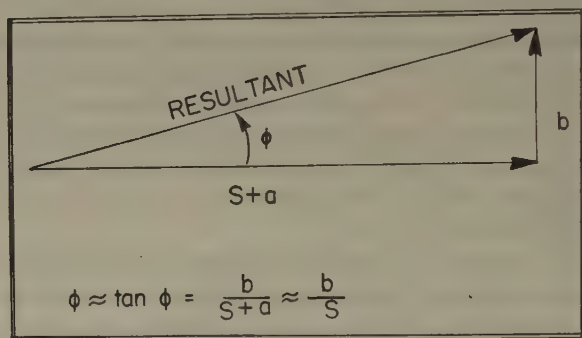

Fig. 17—Simplified vector diagram.

When not all of the signal spectrum is used, the rms error will exceed the limiting value of t_0 computed above.

The burst may be represented by the following Fourier series

$$S(t) = \sum_{k=-k_1}^{k_2} S_k \cos \omega_k t \tag{A-10}$$

where

$$S_k = \left(\frac{1}{2}\, hS_0\right)\cdot d \cdot \left(\frac{\sin dk\pi}{dk\pi}\right) = \frac{hS_0 \sin dk\pi}{2k\pi} \tag{A-11}$$

and

$$\omega_k = \omega_{SC} + k\omega_H. \tag{A-12}$$

Each of these carries timing information; the error associated with the measurement of any component is very nearly Gaussian. For such a case, the Principle of Least Squares[19] may be applied. Then[20]

$$\frac{1}{t_0^2} = \sum_{k=-k_1}^{k_2} \left(\frac{1}{t_{0k}^2}\right) = \sum_{k=-k_1}^{k_2} \left(\frac{S_k}{N_W}\right)^2 (f_W T_M)(2\pi f_k)^2$$

[18] D. Middleton, "Some general results in the theory of noise through non-linear devices," *Quart. Appl. Math.*, vol. V, p. 471; Jan., 1948.

[19] R. B. Lindsay and H. Margenau, "Foundations of Physics," John Wiley & Sons, Inc., New York, N. Y., chap. IV, pp. 159–187; 1936.

[20] D. Richman, "Frame synchronization for color television," *Electronics*, vol. 25, pp. 146–152; Oct., 1952.

$$= \sum_{k=-k_1}^{k_2} \left(\frac{S_0}{N_W}\right)^2 (f_W T_M)(f_{SC} + kf_H)^2 \left(\frac{h \sin dk\pi}{k}\right)^2. \tag{A-13}$$

The factor $(1/t_{0_k}^2)$ has been plotted in Fig. 5(a) as the information per component. The effective accuracy, $1/t_0$ varies as the square root of the area under the curve, for any bandwidth. Although there is an optimum weighting, the weighting is not critical in the vicinity of the correct weighting. This is a general characteristic of integration systems.

Appendix B

Passive Integrators

This appendix presents some equations relevant to the performance of the phase stabilized integrating filter shown in Fig. 6(a).

The basic loop parameters are as follows:

(1) The transfer characteristic of the high Q filter is $F(f)$

$$F(f) \approx \frac{1}{1 + j2\dfrac{f - f_{SC}}{f_{SC}} Q} = \frac{1}{1 + j\dfrac{2\Delta f}{f_s}} = \frac{1}{1 + j\pi \dfrac{\Delta f}{f_N}} = F(\Delta f). \tag{B-1}$$

(2) The phase detector sensitivity, for nominal full amplitude input is $\partial E/\partial \phi$

(3) The passband characteristic of the low pass (dc) filter is $Y(f)$, where $Y(0) = 1$. Let

$$Y(f) = \frac{1}{1 + j2\pi f T}. \tag{B-2}$$

(4) The sensitivity of the phase shifter (assumed broad band) may be represented as

$$\frac{\partial \phi}{\partial E}.$$

(5) The loop gain is G

$$G = \frac{\partial \phi}{\partial E} \cdot \frac{\partial E}{\partial \phi}.$$

(6) The static phase error which would result if there were no feedback is $\Delta\phi_0$

$$\Delta\phi_0 = \arctan\left(-\frac{\pi\Delta f}{f_N}\right) \approx -\frac{\pi\Delta f}{f_N}. \tag{B-3}$$

The Static Phase Error with Feedback

The static phase error with feedback is $\Delta\phi$

$$|F(\Delta f)|\Delta\phi \cdot G \cdot Y_0 = \Delta\phi_0 - \Delta\phi = \Delta\phi_{corr}$$

$$\frac{\Delta\phi}{\Delta\phi_0} = \frac{1}{1 + |F(\Delta f)| G Y_0} \tag{B-4}$$

or, since for normal operation $F(\Delta f) \approx 1$ (very nearly) and $Y_0 \equiv Y(0) = 1$

$$\frac{\Delta\phi}{\Delta\phi_0} = \frac{1}{1 + G}. \tag{B-5}$$

Since $\Delta\phi_0 < 90°$, a loop gain of $G > 17$ makes $\Delta\phi < 5°$ always.

The Effect of the Feedback Loop Upon Noise Performance

When noise is present, the phase detector output produces a noise output, which, after filtering by $Y(f)$ produces extra phase modulation noise.

The equation written earlier can be rewritten in terms of the *phase correction*, $\Delta\phi_{corr}$, since

$$\Delta\phi_{0\ effective} = \Delta\phi_{corr} + \Delta\phi. \tag{B-6}$$

$\Delta\phi_{0\,effective}$ is the equivalent phase modulation to produce the actual phase detector noise output.

Then

$$[\Delta\phi_0(p) - \Delta\phi_{corr}(p)] \cdot G \cdot Y(p) = \Delta\phi_{corr}(p)$$

or

$$\frac{\Delta\phi_{corr}(p)}{\Delta\phi_0(p)} = \frac{GY(p)}{1 + GY(p)} = \frac{G}{1+G}\left[\frac{1}{1 + p\dfrac{T}{1+G}}\right]. \tag{B-7}$$

The signals to the phase detector are

(1) The original composite signal+noise, unfiltered.

(2) The filtered signal, with a narrow band of noise having a very small rms value.

Cross beats of signal upon noise produce considerably larger output than the beatnote between noise components, which are therefore negligible.

The output noise may be expressed as a phase:

$$\frac{b(t)}{S} \approx \Delta\phi_{01}(t) \quad \text{or} \quad \frac{b(p)}{S} \approx \Delta\phi_{01}(p)$$

$$\frac{b(p) \cdot F(\Delta p)}{S} \approx \Delta\phi_{02}(p). \tag{B-8}$$

The total phase noise is $\Delta\phi_{0\,effective} = \Delta\phi^0{}_1 - \Delta\phi_{02}$ since, if the filter $F(f)$ were removed, the phase detector output would be identically zero.

$$\Delta\phi_0(p) = \frac{b(p)}{S}[1 - F(\Delta p)]. \tag{B-9}$$

There is little noise energy below approximately $f_N/2$ appearing at the phase detector output.

Since the transfer characteristic for this noise is

$$\frac{\Delta\phi_{corr}}{\Delta\phi_0} = \frac{G}{1+G}\left[\frac{1}{1 + p\dfrac{T}{1+G}}\right] \tag{B-10}$$

(which corresponds to a low pass filter), the following design condition may be employed to insure that the effective Q of the crystal filter will not be degraded by the feedback

$$\frac{1+G}{2\pi T} < \frac{f_N}{2}$$

or
$$T > \frac{1+G}{\pi f_N}. \tag{B-11}$$

Transient Analysis

The response to a step in differential phase $\Delta\phi_0$, is $\Delta\phi(p)$ or $\Delta\phi(t)$

$$\frac{\Delta\phi(p)}{\Delta\phi_0} = \frac{1}{p}\left[\frac{1+pT}{1+FG+pT}\right]$$
$$= \frac{1}{pT}\left[\frac{1}{\frac{1+FG}{T}+p}\right] + \frac{1}{\frac{1+FG}{T}+p} \tag{B-12}$$

$$\frac{\Delta\phi(t)}{\Delta\phi_0} = \int_0^t \left[\frac{1}{T}\,\epsilon^{-[1+FG/T]t}\right] dt + \epsilon^{-[1+FG/T]t}$$
$$= \frac{1}{1+FG}\left[1-\epsilon^{-[1+FG/T)]t}\right] + \epsilon^{-[1+FG/T]t}$$
$$= \frac{1}{1+FG} + \frac{FG\quad \epsilon^{-[1+FG/T]t}}{1+FG} \tag{B-13}$$
$$= \text{steady state} + \text{transient response.}$$

For $FG \gg 1$, the transient term is negligible for $t > T$.

The time for the phase error to settle down to twice its final value may be computed, as a measure of stabilization time.

The total transient time consists effectively of an amplitude and phase transient of the high Q filter plus the transient time of the feedback loop. The transient is effectively completed in three times the time constant of the filter. Since the noise bandwidth is f_N, the time is

$$T_A \approx 3\left(\frac{1}{4f_N}\right). \tag{B-14}$$

This overlaps with the phase loop transient time, which, neglecting amplitude effects, would be

$$T_\phi = \frac{1}{\pi f_N}\, lnG \approx \frac{1}{\pi f_N}\, ln\left[\frac{\pi\Delta f_{\max}}{f_n\Delta\phi_{\max}} - 1\right] \tag{B-15}$$

which is based on

$$\frac{\Delta\phi}{\Delta\phi_0} = \frac{1}{1+G}\left[1+G\epsilon^{-(1+G)(t/T)}\right]$$
$$G = \frac{\Delta\phi_0}{\Delta\phi_\infty} - 1 \approx \frac{\pi\Delta f_{\max}}{f_N\Delta\phi_{\max}} - 1$$
$$T = \frac{1+G}{\pi f_N}.$$

These two pull-in times overlap.

Appendix C

Performance Characteristics of the Standard APC Loop

This appendix presents a description of the operating characteristics of a standard APC system. The basic parameters of the APC loop are defined. The independence of the primary parameters $\Delta\phi$ (the static phase error) and f_{NN} (the APC loop noise bandwidth) is shown; these parameters characterize the performance after the system has stabilized. The limitations of pull-in are discussed and some formulas which are derived later in Appendix D are introduced. The simple relation presented earlier for pull-in time is then obtained.

The formulas derived may be applied for designs based on any convenient set of assumed criteria.

The Basic APC Loop Parameters

(1) The output voltage ΔE of the phase detector, and the phase difference $\Delta\phi$ between the reference oscillation and the signal are related by the control characteristics. When both signals are sinusoidal,

$$\Delta E = \mu \sin \Delta\phi \tag{C-1}$$

where ΔE is a voltage developed at the phase detector output in response to a phase difference $\Delta\phi$ between signal and reference oscillation. For operation at or very near balance,

$$\frac{\partial E}{\partial\phi} = \mu \qquad \text{volts per radian.}$$

(2) The transfer characteristic of the feedback loop filter is denoted by

$$N(\omega) = \frac{\text{output voltage}}{\text{input voltage}}$$

(3) The sensitivity of the reactance tube is denoted by

$$\beta = \frac{\partial f}{\partial E} \qquad \text{cycles per second per volt.}$$

(4) The factor $|\mu\beta| \equiv f_c$ is a characteristic parameter of the loop; the time constant $t_c \equiv 1/2\pi f_c$ is the transient time constant of the loop when $N(\omega) \equiv 1$. (This may be verified from (C-3) for $Q(\omega)$ presented later.)

(5) The static phase error, $\Delta\phi$, which results from a "free-running" frequency difference, Δf, between signal and local oscillator may be found from the preceding relations:

$$-\sin\Delta\phi = 2\pi\cdot\Delta f\cdot t_c = \frac{\Delta f}{f_c}. \tag{C-2}$$

Although (C-2) contains the appropriate signs, it is the magnitudes of the above quantities which are of interest in design work.

(6) The phase following ratio for an APC loop is

$$\frac{\text{phase variation of output phase}}{\text{phase variation of input phase}} = Q(\omega) = \frac{N(\omega)}{N(\omega)+pt_c}. \tag{C-3}$$

This is the small signal form of the differential equation which characterizes the APC loop. It is used to determine the response of the APC system to noise, after the system is synchronized.

(7) The noise bandwidth of the APC system is f_{NN}. Consistent with the usual practice, this is defined as

$$f_{NN} = \int_0^\infty |Q(\omega)|^2 df = \int_0^\infty Q(\omega)Q(-\omega)df. \quad \text{(C-4)}$$

Representative network configurations for $N(\omega)$ are shown in Fig. 18(a). For each of these networks

$$N(\omega) = \frac{1 + xpT}{1 + (1 + x)pT} \quad \text{(C-5)}$$

where $T=RC$ and $p=j2\pi f=j\omega$. Then

$$Q(\omega) = \frac{1 + xpT}{1 + p(t_c + xT) + p^2(1 + x)t_cT} \cdot \quad \text{(C-6)}$$

This equation suggests one manner in which the meaning of the phase transfer ratio and noise bandwidth of an APC loop may be readily visualized. Fig. 18(b) represents a network having a voltage transfer characteristic which is identical with $Q(\omega)$ given above. If a voltage

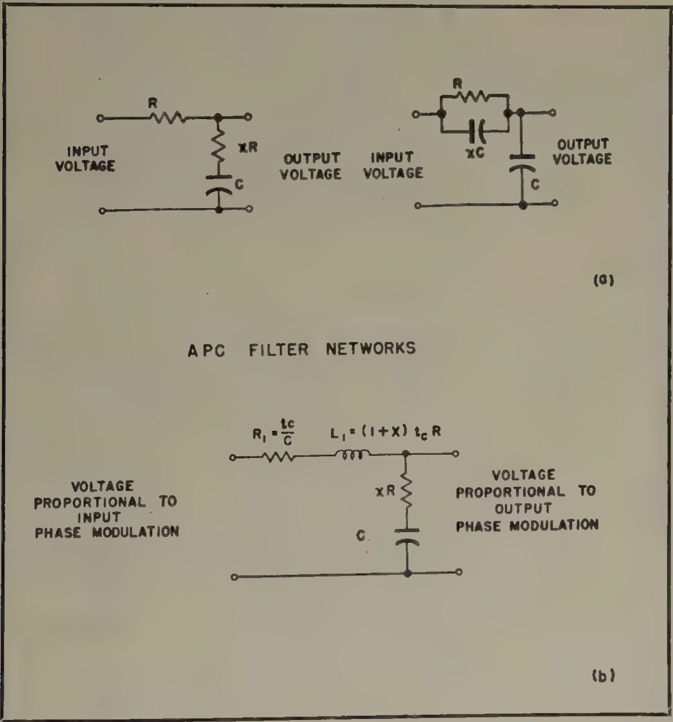

Fig. 18—Equivalent network representing phase following ratio of an APC loop.

proportional to the phase modulation of the synchronizing signal (by noise or any other disturbance) is applied to the input of the network of Fig. 18(b), the output voltage is proportional to the phase modulation of the reference oscillator of the APC loop. The shape of the (low frequency) passband described by $Q(\omega)$ defines the small signal transient response of the loop as well as the noise bandwidth.

(8) The ratio of ac gain/dc gain through the network $N(\omega)$ is

$$m \equiv \frac{x}{1 + x} \quad \text{(C-7)}$$

(from [C-5] when $pT \gg 1$). The parameter m determines the pull-in range of the APC system, when certain other parameters are specified. It is convenient therefore to express the synchronous performance in terms of m.

Also, the term xT/t_c appears often. This is written as

$$y \equiv \frac{xT}{t_c} \cdot \quad \text{(C-8)}$$

Then, rewriting the earlier expressions in terms of these parameters,

$$N(\omega) = \frac{1 + pyt_c}{1 + p\dfrac{y}{m}t_c} \quad \text{(C-9)}$$

$$Q(\omega) = \frac{1 + pyt_c}{1 + pt_c(1 + y) + p^2\dfrac{y}{m}t_c^2} \cdot \quad \text{(C-10)}$$

The noise bandwidth is found by integration (at the end of this Appendix C), using the definition presented earlier, to be

$$f_{NN} = \frac{1}{4t_c} \cdot \frac{1 + my}{1 + y} \cdot \quad \text{(C-11)}$$

(9) In order to prevent resonant ringing on noise impulses, $Q(\omega)$ should have a moderately flat graph. Since the denominator of $Q(\omega)$ contains a quadratic expression, it is convenient to define a damping coefficient, K, which is defined by the following equation:

$$(1 + y)^2 = K \cdot \frac{4y}{m} \cdot \quad \text{(C-12)}$$

Then $K=1$ corresponds to equal roots or critical damping, $K>1$ corresponds to overdamping and makes $Q(\omega)$ approach the shape of the single (RC) low pass filter, and $K<1$ tends to give $Q(\omega)$ a high resonant rise.

Fig. 19 shows the shapes of $|Q(\omega)|$ and $|Q(\omega)|^2$ for several values of K, and subject to the simplifications $y \gg 1$, and $my \approx 4K$, derived below. A value of K close to 1 gives best performance.

The Synchronous Performance of the APC System

The basic equations relating to the synchronous performance of the APC system have been presented above. These are

$$-\sin \Delta\phi = 2\pi \cdot \Delta f \cdot t_c \quad \text{(C-2)}$$

$$f_{NN} = \frac{1}{4t_c} \cdot \frac{1 + my}{1 + y} \quad \text{(C-11)}$$

$$m = \frac{4Ky}{(1 + y)^2} \cdot \quad \text{(C-12)}$$

Since both tight static phase and narrow noise bandwidth are desired, it is possible to define a figure of merit for the system as $|(\sin \Delta\phi)/(\Delta f)| \cdot f_{NN}$; the smaller this product is, the better the over-all performance. However, relations above show that any arbitrarily selected

figure of merit may be obtained by proper design, since, combining the above relations,

$$\left|\frac{\sin \Delta\phi}{\Delta f}\right| \cdot f_{NN} = \frac{\pi}{2}\left[\frac{1+\dfrac{4Ky^2}{(1+y)^2}}{1+y}\right]. \quad \text{(C-13)}$$

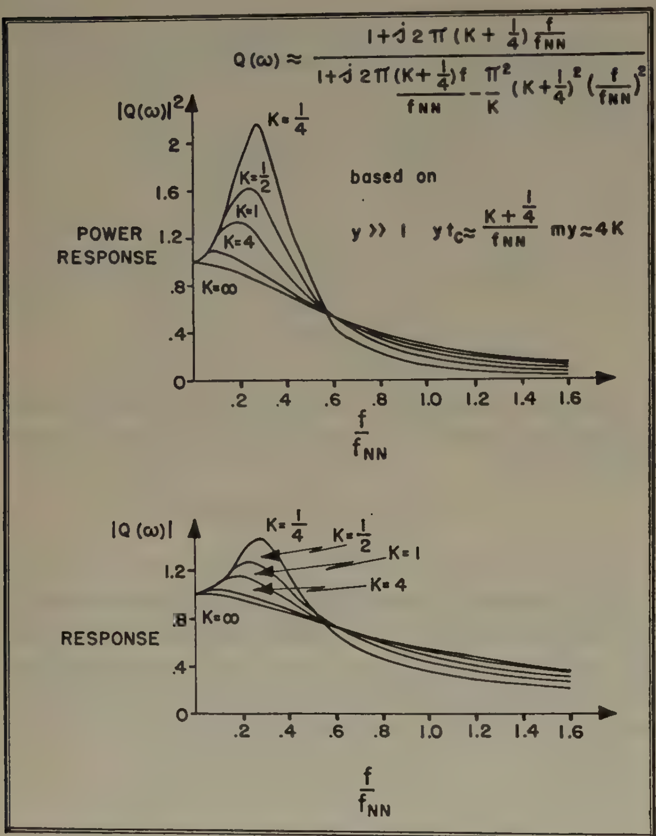

Fig. 19—APC loop small signal modulation response.

For the limiting case of a single time constant filter, $y=0$, and then

$$\left[\left|\frac{\sin \Delta\phi}{\Delta f}\right| \cdot f_{NN}\right]_{y=0} = \frac{\pi}{2}. \quad \text{(C-14)}$$

Thus for the simplified filter the static phase shift and noise bandwidth are interdependent.[21,22] However, for the filters of Fig. 18a, the parameters can be designed for whatever figure of merit is required for synchronous operation.

The above relations may usefully be written in simpler form, since, for the design ranges of interest, $m \ll 1$ and $y \gg 1$; then, very nearly $4K = my$ and hence

$$4f_{NN}t_c = m\frac{1+my}{m+my} \approx m\left(\frac{1+4K}{4K}\right). \quad \text{(C-15)}$$

This equation will be used in expressing the pull-in performance of the system conveniently.

[21] T. S. George, "Analysis of synchronizing systems for dot-interlaced color television," Proc. I.R.E., vol. 39, pp. 124–131; Feb., 1951.

[22] K. Schlesinger, "Locked oscillator for television synchronization," *Electronics*, vol. 22, pp. 112–118; Jan., 1949.

The figure of merit may be written as

$$\left|\frac{\sin \Delta\phi}{\Delta f}\right| f_{NN} = \frac{f_{NN}}{f_c} \approx \frac{\pi}{2}\cdot m\left(\frac{1+4K}{4K}\right). \quad \text{(C-16)}$$

The Transient (Pull-In) Performance

The pull-in behavior of the APC system is investigated in detail in Appendix D. The significant conclusions are as follows: The pull-in performance is expressible in terms of the relations between the parameters

$$\left(\frac{T_F}{xT}\right) \equiv \left(\frac{T_F}{yt_c}\right)$$

and

$$\left|\frac{\Delta f}{mf_c}\right|.$$

Fig. 20 shows the relation between these parameters.

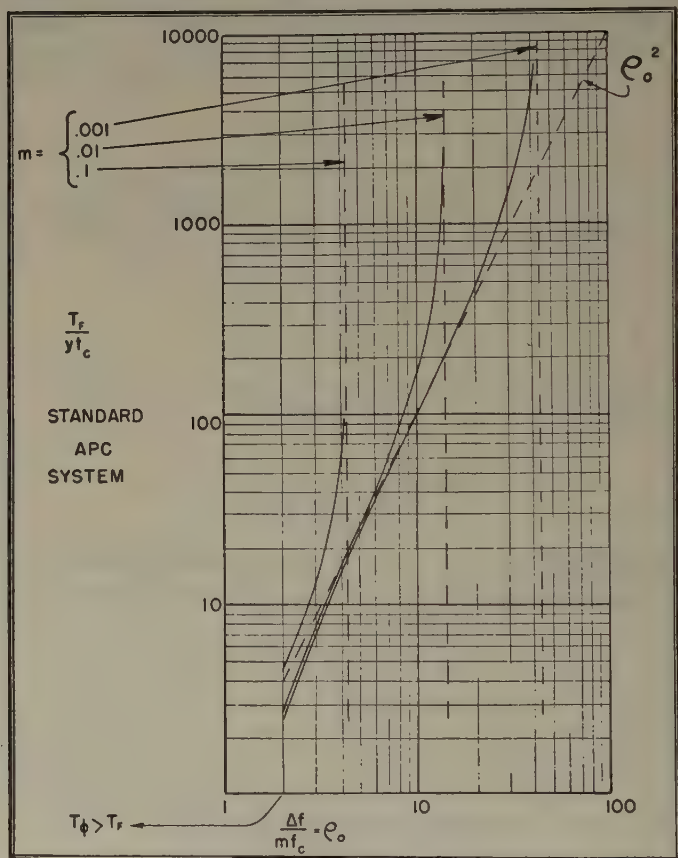

Fig. 20—Universal frequency pull-in characteristics.

The following approximation to the data represented by Fig. 20, based on (D-29), has been found useful in design work, it can also be solved for Δf:

$$T_F \approx xT\frac{\left(\dfrac{\Delta f}{mf_c}\right)^2}{1-\dfrac{\Delta f^2}{2f_c\cdot mf_c}}.$$

If $|\Delta f/mf_c| \leqq 1$ the frequency pull-in is effectively instantaneous ($T_F=0$) but a short period is required for the phase to approach closely its stable value. If $|\Delta f/mf_c| > 1$, the system can slip cycles; often the slip is a great many cycles as this pull-in mechanism is fairly inefficient. The pull-in range is limited to the region

$$\left|\frac{f}{mf_c}\right| < \sqrt{\frac{2}{m} - 1} \qquad \text{(C-17)} \quad \text{(D-25)}$$

or

$$\Delta f_{\max} = f_c\sqrt{2m - m^2} \approx \sqrt{2f_c \cdot mf_c}$$

Then,

$$|\sin \Delta\phi| \approx |\Delta\phi| \leqq \left|\frac{\Delta f_{\max}}{f_c}\right| = m\sqrt{\frac{2}{m} - 1} \approx \sqrt{2m}. \qquad \text{(C-18)}$$

If $m < (1/250)$ the phase angle after pull-in will always be less than 5°. However, not all of the pull-in range is normally used. If

$$|\Delta\phi| < \frac{1}{2}\Delta f_{\max},\ m < \frac{1}{62} \text{ makes } |\Delta\phi| < 5°.$$

When operation is *well within* the pull-in range the *frequency pull-in* time, T_F, which is defined as the time for the oscillator to be pulled from $|\Delta f|$ to within mf_c of the frequency of the color burst, approaches very nearly the relation

$$\frac{T_F}{yt_c} = \left(\frac{\Delta f}{mf_c}\right)^2. \qquad \text{(C-19)} \quad \text{(D-28)}$$

By making m smaller and f_c larger it is possible to extend the pull-in range far enough so that the gated nature of the signal provides the only real limitation on pull-in; the range is $|\Delta f| < (f_H/2)$. The pull-in time is then expressed by the square law relation above, except near the limit of the pull-in range. Furthermore, making m smaller improves the synchronous figure of merit.

The pull-in relations may be expressed in terms of f_{NN}, since

$$yt_c = my\frac{t_c}{m} \approx 4K\cdot\frac{1}{4f_{NN}}\left(\frac{1 + 4K}{4K}\right) = \frac{K + 1/4}{f_{NN}} \qquad \text{(C-20)}$$

and

$$mf_c = \frac{m}{2\pi tc} \approx \frac{1}{2\pi}\cdot 4f_{NN}\frac{4K}{1 + 4K}$$
$$= \frac{2}{\pi}\left(\frac{K}{K + 1/4}\right)\cdot f_{NN} \qquad \text{(C-21)}$$

the following equation results

$$T_F f_{NN} = \lambda^2\left(\frac{\Delta f}{f_{NN}}\right)^2 \qquad \text{(C-22)}$$

where, when f_c is large enough so that $\Delta f_{\max} \gg \Delta f$,

$$\lambda^2 \equiv \left(\frac{\pi}{2}\right)^2\frac{(K + 1/4)^3}{K^2} \geqq 4.2. \qquad \text{(C-23)}$$

The approximate value 4 has been used in Figs. 8 and 9. Fig. 21 shows graphically the relation between K and λ^2. The curve has a minimum at $K = 1/2$.

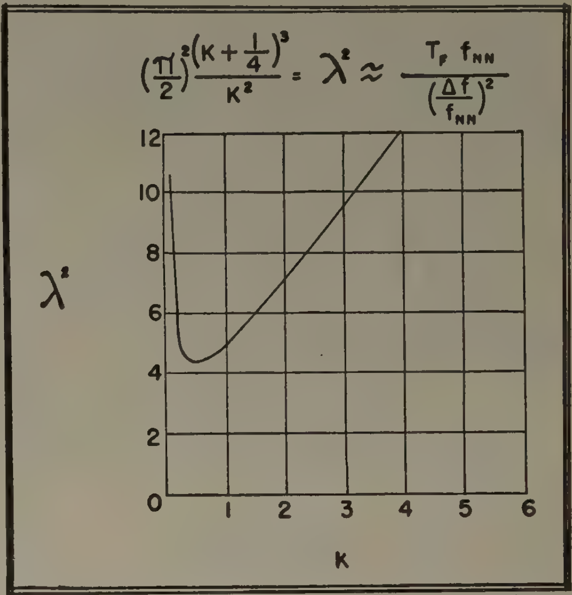

Fig. 21—Graph showing the relation between the damping coefficient, K, and the constant in the APC limit curve equation.

In view of the shape of the curve, and the normal tolerance variations of practical circuits, a value of K near 1 seems desirable. This gives good small signal transient response also. The problem of optimum design is discussed in more detail in a reference.[23]

Derivation of the Noise Bandwidth

The integration is performed as follows. Since

$$Q(p) = \left[\frac{1 + pyt_c}{\frac{m}{y} + pt_c(1 + y)\frac{m}{y} + p^2t_c^2}\right]\left(\frac{m}{y}\right), \qquad \text{(C-10)}$$

then

$$|Q^2| = Q\cdot Q^* = \left(\frac{m}{y}\right)^2\frac{1 + y^2\theta^2}{(\theta^2 + \theta_\alpha^2)(\theta^2 + \theta_\beta^2)} \qquad \text{(C-24)}$$

where

$$\theta = \omega t_c \qquad \text{(C-25)}$$

and

$$\theta_{\alpha,\beta} = \frac{1}{2}\left\{(1+y)\frac{m}{y} \pm \sqrt{\left[(1+y)\frac{m}{y}\right]^2 - 4\frac{m}{y}}\right\} \qquad \text{(C-26)}$$

but

[23] D. Richman, "APC color sync for NTSC color television," IRE Convention Record, part 4; presented March 23, 1953.

$$\frac{1+y^2\theta^2}{(\theta^2+\theta_\alpha^2)(\theta^2+\theta_\beta^2)}=\left[\frac{1-y^2\theta_\alpha^2}{\theta^2+\theta_\alpha^2}-\frac{1-y^2\theta_\beta^2}{\theta^2+\theta_\beta^2}\right]\cdot\frac{1}{\theta_\beta^2-\theta_\alpha^2}. \qquad \text{(C-27)}$$

The above is substituted in (C-4) to give

$$\int_0^\infty Q^2(ft_c)d(ft_c) = t_cf_{NN} \qquad \text{(C-28)}$$

$$=\frac{\left(\frac{m}{y}\right)^2}{\theta_\beta^2-\theta_\alpha^2}\int_0^\infty\left[\frac{1-y^2\theta_\alpha^2}{\theta_\alpha^2+(2\pi ft_c)^2}-\frac{1-y^2\theta_\beta^2}{\theta_\beta^2+(2\pi ft_c)^2}\right]d(ft_c).$$

Then, since d/dx arctan $x=1/(1+x^2)$ and arctan $0=0$, and arctan $\infty=\pi/2$.

$$t_cf_{NN}=\left(\frac{m}{y}\right)^2\left(\frac{\frac{1-y^2\theta_\alpha^2}{4\theta_\alpha}-\frac{1-y^2\theta_\beta^2}{4\theta_\beta}}{\theta_\beta^2-\theta_\alpha^2}\right). \qquad \text{(C-29)}$$

This is simplified as follows. Since

$$\theta_\alpha+\theta_\beta=\frac{m}{y}(1+y) \qquad \text{(C-30)}$$

and

$$\theta_\alpha\cdot\theta_\beta=\frac{m}{y},$$

then

$$t_cf_{NN}=\left(\frac{m}{y}\right)^2\cdot\frac{1}{4}\left[\frac{\frac{\theta_\beta-\theta_\alpha}{\theta_\beta\theta_\alpha}+y^2(\theta_\beta-\theta_\alpha)}{(\theta_\beta-\theta_\alpha)(\theta_\beta+\theta_\alpha)}\right] \qquad \text{(C-11)}$$

$$=\frac{1}{4}\frac{m^2}{y^2}\left[\frac{\frac{y}{m}+y^2}{\frac{m}{y}(1+y)}\right]=\frac{1}{4}\left(\frac{1+my}{1+y}\right).$$

This is the desired result.

Appendix D

Transient Performance of the APC Loop

This appendix provides a description and derivation of formulas relating to pull-in characteristics and pull-in time of APC loops. Exact analysis of a simplified APC loop provides useful formulas and a basis for understanding some of the phenomena relating to pull-in. This then suggests a simple approximate method for reducing the differential equation of the loop to a form which is readily solvable for the pull-in time. The results are plotted and discussed.

The Simplified Loop

The simplest form of APC network is the one for which $N(\omega)=$a constant. See Fig. 22(a).

The basic equations are:

$$N(\omega) = m$$

$$Q(\omega)=\frac{m}{m+pt_c}$$

$$f_{NN}=\frac{\pi}{2}mf_c \qquad \text{(D-1)}$$

$$|\sin\Delta\phi|=\left|\frac{\Delta f}{mf_c}\right|\leq 1.$$

The differential equation of the loop is

$$m\cdot\omega_c\sin\phi=\frac{d\phi}{dt}-\Delta\omega. \qquad \text{(D-2)}$$

The same equation has been shown applicable for directly synchronized oscillators.[24]

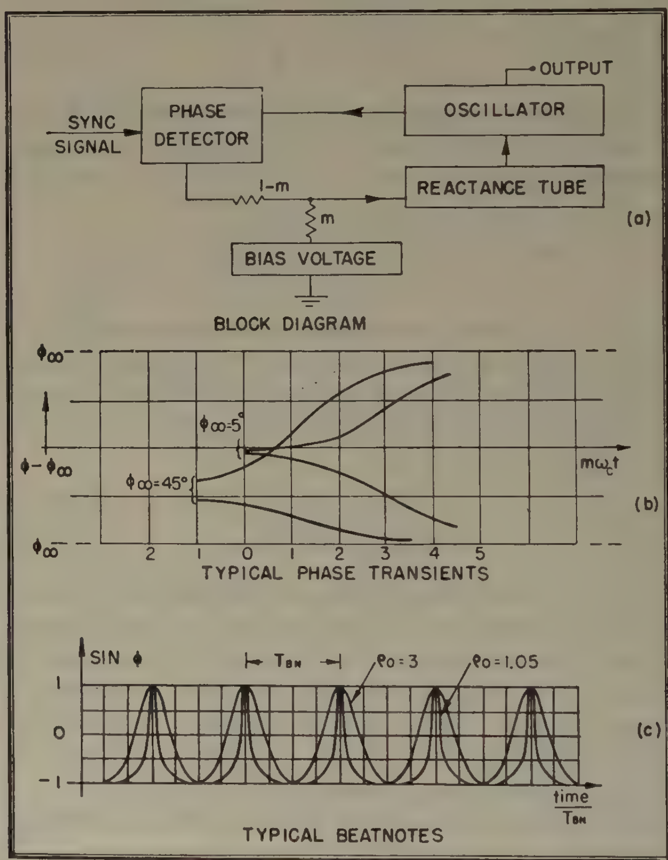

Fig. 22—Basic APC system.

This equation is equivalent to

(Filter transfer characteristic)·(Phase detector output)
= (Rate of change of phase difference)
− (Initial angular frequency difference).

The equation may be rewritten as

$$dt=\frac{d\phi}{\Delta\omega+m\omega_c\sin\phi}. \qquad \text{(D-3)}$$

It has two solutions, depending on whether $\Delta\omega/m\omega_c$ is greater than or less than 1. Boundary conditions are

[24] R. Adler, "A study of locking phenomena in oscillators," Proc. I.R.E., vol. 34, pp. 351–357; June, 1946.

$$t = 0 \qquad \frac{d\phi}{dt} = \Delta\omega \qquad \phi = \phi_0$$

$$t = \infty \qquad \frac{d\phi}{dt} = 0 \qquad \phi = \phi_\infty = \arcsin\left(\frac{-\Delta f}{mf_c}\right). \tag{D-4}$$

Equation (D-3) is directly integrable.[25]

The pull-in range is $\Delta f \leq mf_c$. Within the pull-in range the phase stabilizes according to the following equation, which is the integral of (D-3) under this condition:

$$m\omega_c t \cos \phi_\infty = \ln \left| \frac{\tan \frac{\phi}{2} - \cot \frac{\phi_\infty}{2}}{\tan \frac{\phi}{2} - \tan \frac{\phi_\infty}{2}} \right| \cdot \left| \frac{\tan \frac{\phi_0}{2} - \tan \frac{\phi_\infty}{2}}{\tan \frac{\phi_0}{2} - \cot \frac{\phi_\infty}{2}} \right| \tag{D-5}$$

where

$$\frac{\Delta\omega}{m\omega_c} = \rho = -\sin \phi_\infty \qquad (|\rho| < 1) \tag{D-6}$$

and

$$-\sqrt{1 - \rho^2} = \cos \phi_\infty. \tag{D-7}$$

Typical phase transients are shown in Fig. 22(b). Phase is plotted relative to ϕ_∞ with a scale calibrated in units of $m\omega_c t$. The starting point on any curve is determined by $\phi_0 - \phi_\infty$.

An approximate time constant of stabilization is

$$\frac{-1}{m\omega_c \cos \phi_\infty} = \frac{1}{\sqrt{(m\omega_c)^2 - (\Delta\omega)^2}},$$

however, *the actual stabilization time is a function of the initial phase.*

Outside the pull-in range $\rho > 1$, and the phase as a function of time is defined by the following equation, which is the integral of (D-3) for this condition:

$$\frac{m\omega_c t\sqrt{\rho^2 - 1}}{2} = \arctan \left\{ \frac{\rho \tan \frac{\phi}{2} + 1}{\sqrt{\rho^2 - 1}} \right\} \Bigg|_{\phi_0}^{\phi}. \tag{D-8}$$

This represents a cyclic variation characterized by its wave form and its fundamental frequency, f_{BN}.

Fig. 22(c) shows examples of the cyclic relationship between $\sin \phi$ and t, $\rho_0 = \Delta f / mf_c$ being specified as 1.05 or 3. The time scale is normalized to the beatnote period $T_{BN} = 1/f_{BN}$. The period T_{BN} is such that t increases by T_{BN} when ϕ increases by 2π, and is found from the following relation:

$$\frac{m\omega_c T_{BN}\sqrt{\rho^2 - 1}}{2} = \pi \quad \text{when} \quad \Delta\phi = 2\pi. \tag{D-9}$$

Then

$$T_{BN} = \frac{2\pi}{m\omega_c\sqrt{\rho^2 - 1}} = \frac{1}{\sqrt{(\Delta f)^2 - (mf_c)^2}}. \tag{D-10}$$

This is an important relationship. It states for example, that if in the APC loop block diagram presented above the bias is adjusted so that the effective open loop frequency difference is $\Delta f (> mf_c)$, the operating beatnote frequency difference is $\sqrt{(\Delta f)^2 - (mf_c)^2}$. If the bias is a slowly varying function of time (as compared to f_{BN}), the above relationship accurately describes the variation of f_{BN} with time.

The dc bias or average dc potential developed at the reactance tube input may be determined from the above relationships. It may be expressed in terms of its effect on frequency.

Integrating the differential equation over a cycle, and dividing by the period

$$\frac{1}{T_{BN}} \oint m\omega_c \sin \phi dt = \frac{1}{T_{BN}} \oint \frac{d\phi}{dt} dt - \frac{1}{T_{BN}} \oint \Delta\omega dt \tag{D-11}$$

or

$$m\omega_c \overline{\sin \phi} = \frac{2\pi}{T_{BN}} - \Delta\omega \tag{D-12}$$

and therefore, dividing by 2π,

$$mf_c \overline{\sin \phi} = \sqrt{(\Delta f)^2 - (mf_c)^2} - \Delta f. \tag{D-13}$$

This is plotted in Figs. 11(a) and 23(a) which represents magnitude of the developed bias as a function of Δf.[26] In the standard loop shown later in which the bias battery is replaced by a capacitor it is proportional to the control effect which causes pull-in.

Fig. 23(a) shows that $m\omega_c \overline{\sin \phi}$, the average angular frequency shift, is a maximum when $\Delta\omega / m\omega_c = 1$ and decreases beyond that point, approaching zero asymptotically. When $(\Delta\omega / m\omega_c) < 1$, the phase does not shift 2π radians in a finite time. Enough bias is produced however, to shift the angular frequency by $\Delta\omega$. This bias is represented by the straight line portion, as discussed with regard to Fig. 11(a).

The Standard APC Loop

The standard APC loop is shown in Fig. 23(b). For the network shown,

$$N(p) = \frac{1 + pyt_c}{1 + p\frac{y}{m}t_c} = m\frac{1 + pyt_c}{m + pyt_c} = m + \frac{1 - m}{1 + p\frac{y}{m}t_c}$$

[25] H. B. Dwight, "Tables of Integrals and Other Mathematical Data," The Macmillan Co., New York, N. Y., Integral 436.00; 1947.

[26] In experimental work this characteristic may be measured in terms of f_{BN}. From (D-10), above, $f_{BN}^2 + (mf_c)^2 = (\Delta f)^2$.

= wideband direct transfer component
+ long time-constant integration component
= resistive component
+ capacitive component. (D-14)

The differential equation in operational form is

$$N(p)\omega_c \sin\phi = p\phi - \Delta\omega \tag{D-15}$$

which may be written as

$$m\omega_c \sin\phi = p\phi - \Delta\omega - \frac{1-m}{1+p\dfrac{y}{m}t_c}\,\omega_c \sin\phi. \tag{D-16}$$

The term

$$\Delta\omega + \frac{1-m}{1+p\dfrac{y}{m}t_c}\,\omega_c \sin\phi \equiv \omega_I \tag{D-17}$$

is the Fourier transform of a time function representing effective instantaneous impressed frequency difference.

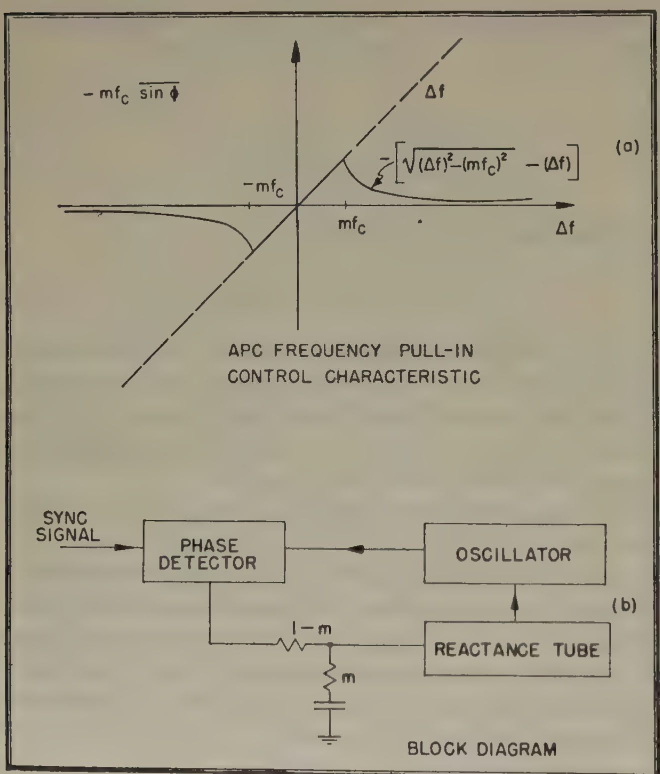

Fig. 23—Standard APC loop.

When this loop is turned on, or has a signal applied to it, the transient of stabilization lasts for a period of time which depends on both the initial phase and the frequency difference. However, the initial phase has only a small effect on the pull-in time and may be neglected for simplicity; the phase transient time, T_ϕ is rapid compared to the frequency pull-in time, T_F. Fig. 22(b) substantiates that for high dc loop gain ($\phi_\infty \ll 90°$) normally $m\omega_c T_\phi < 10$. Then, using (C-15),

$$10 > m\omega_c T_\phi = 4f_{NN}T_\phi\frac{K}{K+\frac{1}{4}}\cdot \tag{D-18}$$

If $K=\frac{1}{2}$, $T_\phi<(15/4f_{NN})$, while if $K=4$, $T_\phi<(2.7/f_{NN})$.

If the frequency difference is such that $\Delta f<mf_c$ the resistive component of loop feedback is adequate to ensure pull-in. The analysis presented above for simplified loop shows the system never slips a complete cycle.

A definition of frequency pull-in time T_F, and phase pull-in time T_ϕ is desirable; the following are useful.

If the system never slips a cycle, then the transient is defined as phase pull-in and measured in terms of the phase pull-in time, T_ϕ.

If the system slips cycles, then the period of time from the instant of switching or excitation until a definable point is reached from which the phase slip does not exceed a cycle is T_F, the frequency pull-in time.

When the initial frequency difference is such that $\Delta f>mf_c$, the long time integration component of feedback must be relied upon for pull-in.

The time constant $(y/m)t_c=y/(2\pi mf_c)$ is long compared to the loop time constant, t_c/m, since $y\gg1$. Because of this long time constant, the average bias across the capacitor which may result from an unsymmetrical beatnote wave form from the phase detector will not change rapidly with time. It is not unreasonable therefore to integrate the differential equation for this APC loop over a cycle of beatnote.

Then

$$m\omega_c\overline{\sin\phi} = \frac{2\pi}{T_{BN}} - \overline{\omega_I} = \sqrt{(\overline{\omega_I})^2-(m\omega_c)^2} - \overline{\omega_I} \tag{D-19}$$

$$\overline{\omega_I} = \Delta\omega + \overline{\frac{1-m}{1+p\dfrac{y}{m}t_c}\,\omega_c\sin\phi}. \tag{D-20}$$

At this point it is necessary to recognize clearly the nature of the signal circulating in the APC loop. There are two components; there is a *cyclic* component produced as a result of the average frequency difference, and having a harmonic composition which is a function of the frequency difference and hence of time during pull-in; there is a low frequency *drift* component which represents the slow change in frequency difference which constitutes pull-in. It has been shown earlier that the generated frequency shift, $\omega_c\overline{\sin\phi}$, varies in an inverse manner with $\Delta\omega$ or $\overline{\omega_I}$; thus, frequency changes slowly except when $\overline{\omega_I}$ is very near $m\omega_c$; stated another way, almost all of the pull-in time is accrued under the condition that the rate of change of the beatnote frequency is not comparable to the beatnote frequency. Therefore, very nearly

$$\oint \frac{1-m}{1+p\dfrac{y}{m}t_c}\,\omega_c\sin\phi\,dt \approx \frac{1-m}{1+p\dfrac{y}{m}t_c}\oint\omega_c\sin\phi\,dt \tag{D-21}$$

and

$$\overline{\frac{1-m}{1+p\dfrac{y}{m}t_c}\omega_c\sin\phi} \approx \frac{1-m}{1+p\dfrac{y}{m}t_c}\omega_c\overline{\sin\phi}. \qquad \text{(D-22)}$$

The term $\omega_c\overline{\sin\phi}$ may be eliminated from the above equations, giving a first order differential equation in $\overline{\omega_I}$, the average angular frequency difference.

$$\overline{\omega_I} - \Delta\omega = \frac{1-m}{1+p\left(\dfrac{y}{m}t_c\right)} \cdot \frac{1}{m}\left[\sqrt{(\overline{\omega_I})^2-(m\omega_c)^2}-\overline{\omega_I}\right]. \qquad \text{(D-23)}$$

This may be written more conveniently, dividing through by $m\omega_c$, writing $\rho=\overline{\omega_I}/m\omega_c$ and $\rho_0=\Delta\omega/m\omega_c$ and by operating on both sides with the differential operator, $1+p(y/m)t_c$.

Then

$$\left(1+p\frac{y}{m}t_c\right)(\rho-\rho_0) = \frac{1-m}{m}\left(\sqrt{\rho^2-1}-\rho\right)$$

or

$$\rho-\rho_0+\frac{y}{m}t_c\frac{d\rho}{dt} = \frac{1-m}{m}\left(\sqrt{\rho^2-1}-\rho\right).$$

Transposing $\rho-\rho_0$ and separating the variables

$$\frac{dt}{\dfrac{y}{m}t_c} = \frac{d\rho}{\rho_0-\rho+\dfrac{1-m}{m}\left(\sqrt{\rho^2-1}-\rho\right)}. \qquad \text{(D-24)}$$

This equation may be directly integrated (between the limits $\rho=\rho_0$ and $\rho=1$) to yield T_F.

The integration is accomplished with the aid of a change of variable which permits the application of some tabulated integrals. The equations obtained are cumbersome; they are presented at the end of this appendix; they were used for the computations on which the several graphs presented are based. Fig. 20 presents the universal pull-in curves for the standard APC system. The following simplified analysis obtains the significant conclusions, in simpler form.

The limiting pull-in range may be determined as the condition which makes the required pull-in time become infinite. This occurs when the denominator of the above integrand has a real root. It will only occur when

$$\rho_0\left(=\frac{\Delta f}{mf_c}\right) \geqq \sqrt{\frac{2}{m}-1}. \qquad \begin{matrix}\text{(D-25)}\\ \text{(C-17)}\end{matrix}$$

A simple approximate solution for the "limit-curve" may be obtained by eliminating from the equation the factor which produces the above limitation. (Specifically, the small term $(\rho_0-\rho)$ in the denominator is omitted.)

Then, if $m\ll 1$, approximately

$$\frac{dt}{yt_c} \approx \frac{d\rho}{\sqrt{\rho^2-1}-\rho} = -\left(\sqrt{\rho^2-1}+\rho\right)d\rho \qquad \text{(D-26)}$$

and hence, integrating from $\rho=\rho_0$ to $\rho=1$,

$$\frac{T_F}{yt_c} = \frac{\rho_0^2-1}{2}+\frac{\rho_0\sqrt{\rho_0^2-1}}{2} - \frac{1}{2}\ln\left|\frac{\rho_0+\sqrt{\rho_0^2-1}}{1}\right|. \qquad \text{(D-27)}$$

Except for ρ_0 near 1, this is closely equal to

$$\frac{T_F}{yt_c} \approx \rho_0^2 = \left(\frac{\Delta f}{mf_c}\right)^2 \qquad \begin{matrix}\text{(D-28)}\\ \text{(C-19)}\end{matrix}$$

which is the equation presented earlier.

The pole at $\rho_0^2=(2/m)-1$ can be included, writing the simplified equation as

$$\frac{T_F}{yt_c} = \frac{\rho_0^2}{1-\dfrac{m}{2-m}\rho_0^2} \qquad 1<\rho_0^2<\left(\frac{2}{m}-1\right). \qquad \text{(D-29)}$$

The exact integration of (D-24) is accomplished with the aid of the following substitution:

$$z=\sqrt{\rho^2-1}-\rho$$

whence,

$$-\rho=\frac{1+z^2}{2z} \quad \text{and} \quad \frac{d\rho}{dz} = -\frac{1}{2}\left(\frac{z^2-1}{z^2}\right).$$

Then

$$\frac{T_F}{yt_c} = \int_{z_0}^{z_1}\frac{-\left(z-\dfrac{1}{z}\right)dz}{(2-m)z^2+2m\rho_0 z+m}. \qquad \text{(D-30)}$$

The limits are

$$\left|\begin{matrix}\rho=1\\ \rho=\rho_0\end{matrix}\right. \quad \text{and} \quad \left|\begin{matrix}z_1=-1\\ z_0=\sqrt{\rho_0^2-1}-\rho_0.\end{matrix}\right.$$

Referring to H. B. Dwight, "Tables of Integrals and Other Mathematical Data,"[25] Integrals #160.01, #160.11 and #161.11 are used.

Then

$$\frac{T_F}{yt_c} = -\left\{\frac{1}{2(2-m)}\ln\left|(2-m)z^2+2m\rho_0 z+m\right| - \frac{1}{2m}\ln\frac{z^2}{(2-m)z^2+2m\rho_0 z+m} + \left[\frac{2m\rho_0}{2}\left(\frac{1}{m}-\frac{1}{2-m}\right)\frac{2}{\sqrt{4(2-m)m-(2m\rho_0)^2}} \cdot \arctan\frac{2(2-m)z+2m\rho_0}{\sqrt{4(2-m)m-(2m\rho_0)^2}}\right]\right\}\Bigg|_{z_0=\sqrt{\rho_0^2-1}-\rho_0}^{z_1=-1}$$

$$= \frac{-1}{2(2-m)} \ln \left| \frac{2(1-m\rho_0)}{(2-m)z_0^2 + 2m\rho_0 z_0 + m} \right|$$
$$+ \frac{1}{2m} \ln \left(\frac{1}{z_0^2}\right) \left[\frac{(2-m)z_0^2 + 2m\rho_0 z_0 + m}{2(1-m\rho_0)} \right]$$
$$- \left\{ 2\rho_0 \left(\frac{1-m}{2-m}\right) \frac{1}{\sqrt{m(2-m)-(m\rho_0)^2}} \right. \tag{D-31}$$
$$\cdot \left[\arctan \frac{m\rho_0 - 2 + m}{\sqrt{m(2-m)-(m\rho_0)^2}} \right.$$
$$\left. \left. - \arctan \frac{m\rho_0 + (2-m)z_0}{\sqrt{m(2-m)-(m\rho_0)^2}} \right] \right\}.$$

Appendix E

Reliability of Frequency Difference Detection

This Appendix presents some mathematical derivations relating to the reliability of frequency difference detection.

The relations between rms frequency error and integration time are derived for

(a) the signal

(b) quadricorrelator frequency difference detector preceded by limiter

(c) quadricorrelator frequency difference detector alone.

Basic Signal Characteristics

The combination of signal and noise may be expressed in the following alternate forms (omitting for the moment the time gate factor)

$$S \cos \omega_{SC} + a(t) \cos \omega_{SC} t + b(t) \sin \omega_{SC} t \tag{E-1}$$

in which the noise is related to the color subcarrier frequency, or

$$S \cos \omega_{SC} t + a_0(t) \cos \omega_0 t + b_0(t) \sin \omega_0 t \tag{E-2}$$

in which the noise is expressed relative to the local oscillator frequency.

After limiting, the signal can be expressed as

$$S \cos (\omega_{SC} t + \phi(t)). \tag{E-3}$$

The phase modulation due to noise is $\phi(t)$.

$$\phi(t) = \arctan \frac{b(t)}{S + a(t)} \approx \frac{b(t)}{S} \tag{E-4}$$

as a first order approximation.

Then

$$\frac{d\phi}{dt} = \frac{S \dfrac{db}{dt} + \dfrac{d}{dt}(ab)}{(S+a)^2 + b^2}. \tag{E-5}$$

As a second order approximation, the relationship

$$\phi(t) = \int \frac{d\phi}{dt} dt \approx \frac{b(t)}{S} + \frac{a(t)b(t)}{S^2} \tag{E-6}$$

can be used, since $(S+a)^2 + b^2 \approx S^2$ for signals of interest.

The instantaneous frequency of the amplitude limited signal is

$$f(t) = \frac{1}{2\pi}\left[\omega_{SC} + \frac{d\phi(t)}{dt}\right]. \tag{E-7}$$

The rms frequency error due to noise is f_{rms}.

$$f_{\text{rms}} = \frac{1}{2\pi}\left[\frac{d\phi(t)}{dt}\right]_{\text{rms}}. \tag{E-8}$$

The signal amplitudes will also be useful in this analysis.

Then

$S = \frac{1}{2}hS_0$ = amplitude of a burst

$Sd = \frac{1}{2}hS_0 d$ = average amplitude of the component at the burst frequency with gate duty cycle d.

The rms value of $b(t)$ is the square root of the noise power. If *effectively* passed through a filter of bandwidth f_H, and gated with a duty cycle d, the noise power per unit time is $d(N_W^2/f_W)f_H$ and hence, the first order approximation for ϕ_{rms} is

$$\phi_{\text{rms}} \approx \frac{b_{\text{rms}}}{S} = \frac{N_W}{\frac{1}{2}hS_0}\sqrt{\frac{f_H}{df_W}}. \tag{E-9}$$

These relations are useful in evaluating the relation between integration time and reliability of the best possible frequency difference detector which might be used for the signal.

To relate reliability to time, the signal information may be averaged over a period T_I, and the rms value of the average then has improved reliability by virtue of integration. As in the case of phase information, it is convenient to use a rectangular time aperture for a standard of comparison for integrators.

Then

$$f_{\text{rms}} = \frac{1}{T_I}\left[\int_0^{T_I} [f(t) - f_{SC}]dt\right]_{\text{rms}} \tag{E-10}$$
$$= \frac{1}{T_I}\left[\int_0^{T_I} \frac{1}{2\pi}\frac{d\phi}{dt}dt\right]_{\text{rms}}$$
$$= \frac{1}{2\pi T_I}[\phi(T_I) - \phi(0)]_{\text{rms}}$$
$$= \frac{\sqrt{2}}{2\pi T_I}\phi_{\text{rms}}$$

and therefore, using the first order approximation above,

$$f_{\text{rms}} \approx \sqrt{\frac{2}{d}} \cdot \frac{1}{h\pi T_I} \cdot \frac{N_W}{S_0} \cdot \sqrt{\frac{f_H}{f_W}}. \tag{E-11}$$

The term $(S_0/N_W)\sqrt{f_W}$ is the signal-to-*noise-density* ratio.

The factor $(1/T_I)\sqrt{f_H}$ has the dimensions of (frequency)$^{3/2}$; such terms normally result in frequency

modulation noise analysis due to the triangular spectrum of the noise.[27]

The second order approximation is

$$f_{\text{rms}} \approx \frac{1}{\sqrt{2}\,\pi T_I}\left[\left(\frac{b_{\text{rms}}}{S}\right)^2 + \left(\frac{(ab)_{\text{rms}}}{S^2}\right)^2\right]^{1/2} \quad \text{(E-12)}$$

Note here that rms values add in quadrature.

The second term varies as

$$\left(\frac{N_W}{S_0}\sqrt{\frac{f_H}{f_W}}\right)^2$$

and for signal-to-noise ratios which at present give satisfactory monochrome video signals is small compared to the first term.

Quadricorrelator with Limiter

The quadricorrelator is shown in Figs. 13 and 14. The quadrature reference is R_Q.

$$R_Q = \sin \omega_0 t. \quad \text{(E-13)}$$

The in-phase reference is R_I.

$$R_I = \cos \omega_0 t. \quad \text{(E-14)}$$

The cosine beatnote is the beatnote between the input signal and R_I. This is conveniently expressed as

$$\frac{2}{S}\,\overline{[S \cos(\omega_{SC}t + \phi)] \cos \omega_0 t}$$
$$= \cos [[\omega_0 - \omega_{SC}]t - \phi(t)]. \quad \text{(E-15)}$$

The sine beatnote is then

$$\frac{2}{S}\,\overline{[S \cos(\omega_{SC}t + \phi)] \sin \omega_0 t}$$
$$= \sin [[\omega_0 - \omega_{SC}]t - \phi(t)]. \quad \text{(E-16)}$$

The derivative of the cosine beatnote is

$$-\left[\omega_0 - \omega_{SC} - \frac{d\phi}{dt}\right] \sin [[\omega_0 - \omega_{SC}]t - \phi(t)]. \quad \text{(E-17)}$$

Let

$$\omega_0 - \omega_{SC} \equiv \Delta\omega \equiv 2\pi\Delta f. \quad \text{(E-18)}$$

Then, the indicated frequency, which is the integrated output from the product of the signals expressed in (E-16) and (E-17), as multiplied in the output synchronous detector of the quadricorrelator, is, with due regard to signs,

$$f(t) = \frac{1}{\pi T_I}\int_0^{T_I}\left[\Delta\omega - \frac{d\phi}{dt}\right] \sin^2 [\Delta\omega t - \phi(t)]dt. \quad \text{(E-19)}$$

The polarity of the indicated frequency may be reversed (when so required) by transferring the differentiating circuit from the cosine channel to the sine channel.

Then, since $\sin^2 x = \frac{1}{2} - \frac{1}{2}\cos 2x$, and since

$$\left[\Delta\omega - \frac{d\phi}{dt}\right] \cos 2[\Delta\omega t - \phi]dt$$
$$= \cos 2[\Delta\omega t - \phi]\cdot d[\Delta\omega t - \phi]$$

we obtain

$$f(t) = \Delta f + \frac{1}{2\pi T_I}\int_{t=0}^{t=T_I} d\phi - \frac{1}{2\pi T_I}\int_{t=0}^{t=T_I} \cos 2\eta d\eta \quad \text{(E-20)}$$

where

$$\eta \equiv \Delta\omega t - \phi(t).$$

Thus the output noise consists of two components: the first represents the frequency noise of the signal; it could be measured as output noise if ω_{SC} were ***known***. The second represents extra noise introduced by the measurement of an unknown frequency in this circuit. Then

$$f_{\text{rms}} = \frac{1}{\sqrt{2}\,\pi T_I}[\phi_{\text{rms}}{}^2 + \text{extra noise}^2]^{1/2}. \quad \text{(E-21)}$$

The extra noise is evaluated as follows:

$$\frac{1}{2\pi T_I}\int_{t=0}^{t=T_I} \cos 2\eta d\eta$$
$$= \frac{1}{2\pi T_I}\left[\tfrac{1}{2}\sin 2\eta(T_I) - \tfrac{1}{2}\sin 2\eta(0)\right]. \quad \text{(E-22)}$$

Two effects are indicated:

(a) Due to the use of a rectangular time aperture, an extraneous "sampling distortion" term appears unless $\Delta\omega T_I$ = a multiple of 2π, which is therefore assumed for simplicity.

(b) The output noise has the character of random noise which is passed through a nonlinear amplifier having a gain proportional to the sine of the input. This crushes the noise peaks and reduces the rms value.

Then, since $\sin^2 x < x^2$

$$\left[\frac{1}{2\pi T_I}\int_{t=0}^{t=T_I} \cos 2\eta d\eta\right]_{\text{rms}} < \frac{\sqrt{2}}{2\pi T_I}\phi_{\text{rms}}. \quad \text{(E-23)}$$

If there is substantial integration ($f_H T_I \gg 1$), the two noise components approach complete independence and add in quadrature, hence at worst,

$$f_{\text{rms}} \approx \frac{1}{\pi T_I}\phi_{\text{rms}}. \quad \text{(E-24)}$$

Thus, the quadricorrelator, with a limiter, measures a frequency difference to within a few db of the ultimate reliability permitted by signal information. It has no "detuning" error. The stepped characteristic may be introduced to give

[27] M. G. Crosby, "Frequency modulation noise characteristics," Proc. I.R.E., vol. 25, pp. 472–514; April, 1937.

$$f_{\mathrm{rms}} \approx \frac{1}{\pi T_I} \phi_{\mathrm{rms}} \sqrt{\frac{f_H - 2f_{NN}}{f_H}} \cdot \qquad \text{(E-25)}$$

Since $f_H \gg 2f_{NN}$, the simpler equations above are adequate.

Quadricorrelator without Limiter

The input signal is

$$S \cos \omega_{SC} t + a_0(t) \cos \omega_0 t + b_0(t) \sin \omega_0 t. \qquad \text{(E-2)}$$

The cosine beatnote is proportional to

$$\cos \Delta\omega t + \frac{a_0(t)}{S} \cdot \qquad \text{(E-26)}$$

The sine beatnote is

$$\sin \Delta\omega t + \frac{b_0(t)}{S} \cdot \qquad \text{(E-27)}$$

The derivative of the cosine beatnote is

$$-\Delta\omega \sin \Delta\omega t + \frac{1}{S}\frac{da_0(t)}{dt} \cdot \qquad \text{(E-28)}$$

The quadricorrelator output is

$$f(t) = \frac{1}{\pi T_I}\int_0^{T_I}\left[\Delta\omega \sin \Delta\omega t - \frac{1}{S}\frac{da_0}{dt}\right] \cdot \left[\sin \Delta\omega t + \frac{b_0}{S}\right] dt$$

$$= \Delta f - \frac{1}{\pi T_I}\int_0^{T_I}\frac{1}{S}\frac{da_0}{dt}\sin \Delta\omega t dt \qquad \text{(E-29)}$$

$$+ \frac{1}{\pi T_I}\int_0^{T_I}\frac{\Delta\omega}{S} b_0 \sin \Delta\omega t dt$$

$$- \frac{1}{\pi T_I}\int_0^{T_I}\frac{1}{S^2} b_0 \frac{da_0}{dt} dt.$$

The evaluation of the several terms is aided by integration by parts:

$$-\frac{1}{\pi T_I}\int_0^{T_I}\frac{1}{S}\frac{da_0}{dt}\sin \Delta\omega t dt$$

$$= -\frac{1}{\pi T_I}\sin \Delta\omega t \frac{a_0}{S}\Bigg|_0^{T_I}$$

$$+ \frac{1}{\pi T_I}\int_0^{T_I}\frac{\Delta\omega}{S} a_0 \cos \Delta\omega t dt. \qquad \text{(E-30)}$$

Then

$$\left[-\frac{1}{\pi T_I}\sin \Delta\omega t \cdot \frac{a_0}{S}\Bigg|_0^{T_I}\right]_{\mathrm{rms}} = \frac{1}{\pi T_I}\cdot\frac{a_{0\mathrm{rms}}}{S} \cdot \qquad \text{(E-31)}$$

The term

$$\frac{1}{\pi T_I}\int_0^{T_I}\frac{\Delta\omega}{S}\left[b_0(t)\sin \Delta\omega t + a_0(t)\cos \Delta\omega t\right] dt \qquad \text{(E-32)}$$

now appears. This is a two-dimensionally noise modulated sine wave, of the type shown in Fig. 16. The bandwidth of the noise, however, is such that it heterodynes with the carrier to produce a dc component. Then, the integral of this term has the rms value

$$\frac{\Delta\omega}{\pi S}\frac{N_{\mathrm{rms}}}{\sqrt{f_H T_I}} = \frac{\Delta\omega}{\pi S}\frac{a_{0\mathrm{rms}}}{\sqrt{f_H T_I}} \qquad \text{(E-33)}$$

since there are $f_H T_I$ effective harmonic components. The remaining term is evaluated as follows, integrating by parts:

$$\left[\frac{1}{\pi T_I}\int_0^{T_I}\frac{a_0}{S^2}\frac{db_0}{dt}dt\right]_{\mathrm{rms}}$$

$$= \left[\frac{1}{\pi T_I}\int_0^{T_I}\frac{b_0}{S^2}\frac{da_0}{dt}dt\right]_{\mathrm{rms}}$$

$$= \frac{1}{\sqrt{2}}\left[\frac{1}{\pi T_I}\int_0^{T_I}\frac{1}{S^2}\frac{d}{dt}(a_0 b_0)dt\right]_{\mathrm{rms}}$$

$$= \frac{1}{\pi T_I}\frac{(a_0 b_0)_{\mathrm{rms}}}{S^2} \cdot \qquad \text{(E-34)}$$

Then

$$[f(t) - \Delta f]_{\mathrm{rms}}$$

$$= f_{\mathrm{rms}} = \frac{1}{\pi T_I}\left[\left[\left(\frac{a_{0\mathrm{rms}}}{S}\right)^2 + \left(\frac{(a_0 b_0)_{\mathrm{rms}}}{S^2}\right)^2\right] + \left[\frac{2\Delta f}{\sqrt{f_H T_I}}\cdot\frac{a_{0\mathrm{rms}}}{S}\right]^2\right]^{1/2} \cdot \qquad \text{(E-35)}$$

These terms add in quadrature as they represent independent random variables. The first bracketed term is of similar form as, but 3 db larger than, the second order signal approximation presented in (E-12), and is nearly equal to

$$\frac{1}{\pi T_I}\frac{a_{0\mathrm{rms}}}{S} \cdot$$

The extra noise due to amplitude modulation appears in the last term of (E-35). The ratio of the AM component of noise to the FM component of noise is near

$$\frac{2\pi \Delta f T_I}{\sqrt{f_H T_I}} \cdot \qquad \text{(E-36)}$$

When Δf is small, the quadricorrelator without a limiter approaches the limit of performance permitted by the signal. When Δf approaches $\frac{1}{2}f_H$, a poorer signal-to-noise ratio is obtained. The time T_I must be selected so that f_{rms} does not exceed some selected value, when Δf is the nominally maximum design value for pull-in range.

Equation (E-35) shows that the operation of pulling in results in a large reduction of output noise from the quadricorrelator.

Table of Symbols

Symbol	*Description*
a, $a(t)$	cosine component of noise at the frequency of the sync signal
a_0, $a_0(t)$	same at frequency of oscillator
b, $b(t)$	sine component of noise at the frequency of the sync signal
b_0, $b_0(t)$	same at frequency of oscillator
C	capacitor, Fig. 18
d	the duty cycle of the burst
f_c	the dc loop gain of an APC system, equal to the peak frequency holding range
f_{BN}	beatnote frequency, appearing in Appendix D
f_H, $f_{\mathrm{HORIZONTAL}}$	the line-scanning frequency, 15,750 cps
f_N	effective noise bandwidth of a phase-detection system
$f_{N_{\mathrm{LIMIT}}}$	the value of f_N if all of the phase information is used
f_0	frequency of the local reference oscillator
f_{NN}	the noise bandwidth of an APC loop
f_{rms}	root-mean-square frequency error of a frequency-difference detector
f_{SC}, $f_{\mathrm{SUBCARRIER}}$	the subcarrier (color carrier) frequency
$f(t)$	indicated frequency difference
f_W	video bandwidth occupied by signal and noise
f_3	the 3 db pass-band width of a high Q filter
$F(f)$	transfer characteristic of high Q filter
$F(\Delta f)$	transfer characteristic of high Q filter measured in terms of frequency difference
G	loop gain of phase-control system of Appendix B
h	the ratio of the peak-to-peak amplitude of the burst and the line and field sync pulses
k	index number used in Appendix A
K	a damping coefficient relating to the pass band of an APC loop
m	the resistive divider ratio of a standard APC filter, the ratio of ac gain over dc gain through the network $N(\omega)$
$N(t)$, N	noise signal as a function of time
N_W	the root-mean-square noise in the entire video pass band, assumed flat over the band
$N(\omega)$, $N(p)$	transfer characteristic of the filter of an APC loop
p	$j\omega$, $j2\pi f$, or d/dt as appropriate
$p(\tau)$	the relative probability density distribution function for timing data
$p(\phi)$	the relative probability density distribution function for phasing data
$Q(f)$, $Q(\omega)$	the effective modulation pass band transfer characteristic of an APC system after synchronization
r	ratio of actual gate width to minimum burst width
R	resistor, Fig. 18
R_I	in-phase reference signal
R_Q	quadrature reference signal
S	amplitude of color burst
S_k	amplitude of kth frequency component
S_0	the amplitude of the line and field sync pulses
$S(t)$	the synchronizing signal as a function of time
T	time constant of low-pass filter $Y(f)$
T	time constant RC of Fig. 18
T_A	transient response time of high Q filter in Appendix B
T_{BN}	beatnote period
t_c	characteristic time constant of an APC loop
T_F	frequency pull-in time
T_I	integration time of a frequency-difference detector
T_M	effective integration time
$T_{M_{\mathrm{LIMIT}}}$	the required value of T_M if all of the phase information is used
t_0	root-mean-square time error
t_0'	root-mean-square error if the color synchronizing signal were present all of the time
t_{0_k}	rms timing error of the k'th frequency component
T_S	stabilization time of a synchronizing system
T_ϕ	phase pull-in time
x	constant relating to Fig. 18(a)
y	parameter defined by (C-8)
$Y(f)$	pass-band characteristic of the low-pass filter in the phase-control system of Fig. 6, Appendix B
z	variable of integration used in Appendix D
β	sensitivity of the reactance tube of an APC loop
ΔE	output voltage of the phase detector of an APC loop
Δf	frequency difference between oscillator and sync signal
$\Delta f_{\max}$	maximum frequency difference from which pull-in will occur
$\Delta\phi$	the static phase error of an APC loop
$\Delta\phi$	as used in Appendix B—phase error of phase feedback system
$\Delta\phi_{\mathrm{corr}}$	the phase correction produced by the phase feedback system of Appendix B
$\Delta\phi_{\mathrm{corr}}(p)$	frequency spectrum of $\Delta\phi_{\mathrm{corr}}$
$\Delta\phi_0$	static phase error of high Q filter
$\Delta\phi_{0_{\mathrm{effective}}}$	equivalent phase modulation (re. B-6)
$\Delta\phi_0(p)$	frequency spectrum of $\Delta\phi_{0_{\mathrm{effective}}}$
$\Delta\phi_{01}(p)$	frequency spectrum of beat between filtered signal and direct noise at the phase detector of Fig. 6(a) (re. B-8)
$\Delta\phi_{02}(p)$	frequency spectrum of beat between the direct signal and filtered noise at the phase detector of Fig. 6(a) (re. B-8)
$\Delta\omega$	angular frequency difference
η	parameter used in Appendix E
θ, θ_α, θ_β	parameters defined and used in Appendix C
λ^2	see (C-23) and Fig. 21
μ	transfer gain of phase detector of an APC loop
$\rho=\dfrac{\Delta f}{mf_c}$	normalized frequency difference defined in Appendix C
ρ_0	initial value of ρ
τ	time scale for a probability density
ϕ	phase angle
ϕ_1	a phase variable relating to Fig. 2(c)
ϕ_{rms}	root-mean-square phase error
ϕ_0	initial phase
ϕ_∞	static phase difference due to frequency detuning
ω_c	$2\pi f_c$
ω_H	$2\pi f_H$
ω_I	instantaneous angular frequency difference (re. D-17)
ω_k	kth angular frequency
ω_0	$2\pi f_0$
ω_{SC}	$2\pi f_{SC}$

The Concept of Transmission Primaries in Color Television*

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Summary—**This paper deals primarily with the concept of color space as a three-dimensional representation of the means for specifying color. It shows the relationship between the various sets of primaries used by the NTSC in its mathematical description of its form of color and transmission and points out that the *I* and *Q* axes, together with Illuminant C, comprise in themselves a set of primaries in color space. This set has been termed the Transmission Primaries.**

IN COLORIMETRY we are accustomed to thinking of matching a given color by a suitable mixture of three primary lights. Any set of three lights may be used as primaries for such color matching, provided no two of them will match the third. They may be physically realizable primaries, such as the red, green, and blue lights used in a color receiver, or hypothetical, nonphysical primaries, such as the $(X)(Y)$ and (Z) "lights" used in the CIE system of color specification.

Two kinds of information must be specified in such a color match: first, the chromaticities of the primaries used, and second, the amount required of each primary. Thus, in a receiver, the voltages applied to the grids of the color tube specify the amounts of the particular red, green, and blue lights used. They say that the color in front of the camera is matched (if we assume a gamma of unity) by E_R units of (R) light, E_G units of (G) light, and E_B units of (B) light. All of this is well known, but is intended to introduce an idea not so well known, namely, that the transmitted signals E_W, E_R-E_W, E_B-E_W, represent the amounts of three other primaries, the transmission primaries (W), $(R-W)$, and $(B-W)$, whose chromaticities may easily be found. The same is true for the more recent set of transmission signals, E_W, E_I, E_Q.

The CIE Color Space

These ideas may be visualized by reference to the CIE color space shown in Fig. 1. The co-ordinate axes of this space represent the CIE primaries, $(X)(Y)(Z)$. Any color may be represented as a point somewhere in this space, its location being determined by the amounts, X, Y, Z, of the CIE primaries required to match it. In other words, the $(X)(Y)(Z)$ axes are a conventional set of cartesian axes for the color space.

Any mixture of these three primaries in the same *ratio* will produce light of the same chromaticity, regardless of the actual amounts used. This means that all lights of the same chromaticity lie on a line passing through the origin. The direction of the line specifies the chromaticity, so chromaticity could be given as two angles, say the azimuth and elevation of the line joining the origin to the color point, or as the direction cosines of this line. However, for a more convenient and useful specification of the direction of this color vector, the unit plane

$$X + Y + Z = 1$$

is constructed. The direction is then specified by the X and Y co-ordinates (x, y) of the point at which the color vector pierces this plane. Fig. 1 shows this unit chromaticity plane, and on it the spectrum locus, the NTSC color triangle, and Illuminant C white. Since the Z co-ordinate on the unit plane is dependent on the values of X and Y, it is unnecessary to include it in the specification of chromaticity. Accordingly the chromaticity diagram on the unit plane is projected in the Z direction onto the XY plane, giving us the CIE chromaticity diagram as we normally see it.

Since we are dealing with a "constant-luminance" system in which the signals transmitted on the color subcarrier are intended to affect chromaticity without changing the luminance, we are often interested in plotting chromaticity information at constant luminance. The CIE primary (Y) provides all the luminance of a color mixture, primaries (X) and (Z) having zero luminance. The XZ plane is therefore a plane of zero luminance, and planes parallel to it (Y=constant planes) are planes of constant luminance. Such a constant luminance plane is shown in Fig. 1. The transfer of chromaticity data from the CIE chromaticity diagram to this plane is accomplished by two projections indicated in Fig. 1; first a projection in the Z direction from the chromaticity diagram to the unit plane, and then a projection from the origin to transfer the chromaticity data from the unit plane to the constant luminance plane. Note that the blue primary, having a small luminosity coefficient, projects upward at a very shallow angle and will not reach the constant luminance plane shown for quite a distance beyond the edge of the drawing.

NTSC Transmission Primaries

In the CIE color space the $(X)(Y)(Z)$ co-ordinate axes represent "lights" of constant chromaticity which are used as primaries. However, any other set of three straight lines through the origin which may be used as a new set of co-ordinate axes represents three new lights of constant chromaticity which may also be used as primaries. If these lines lie inside the spectrum locus, the primaries are physically realizable, if outside, they

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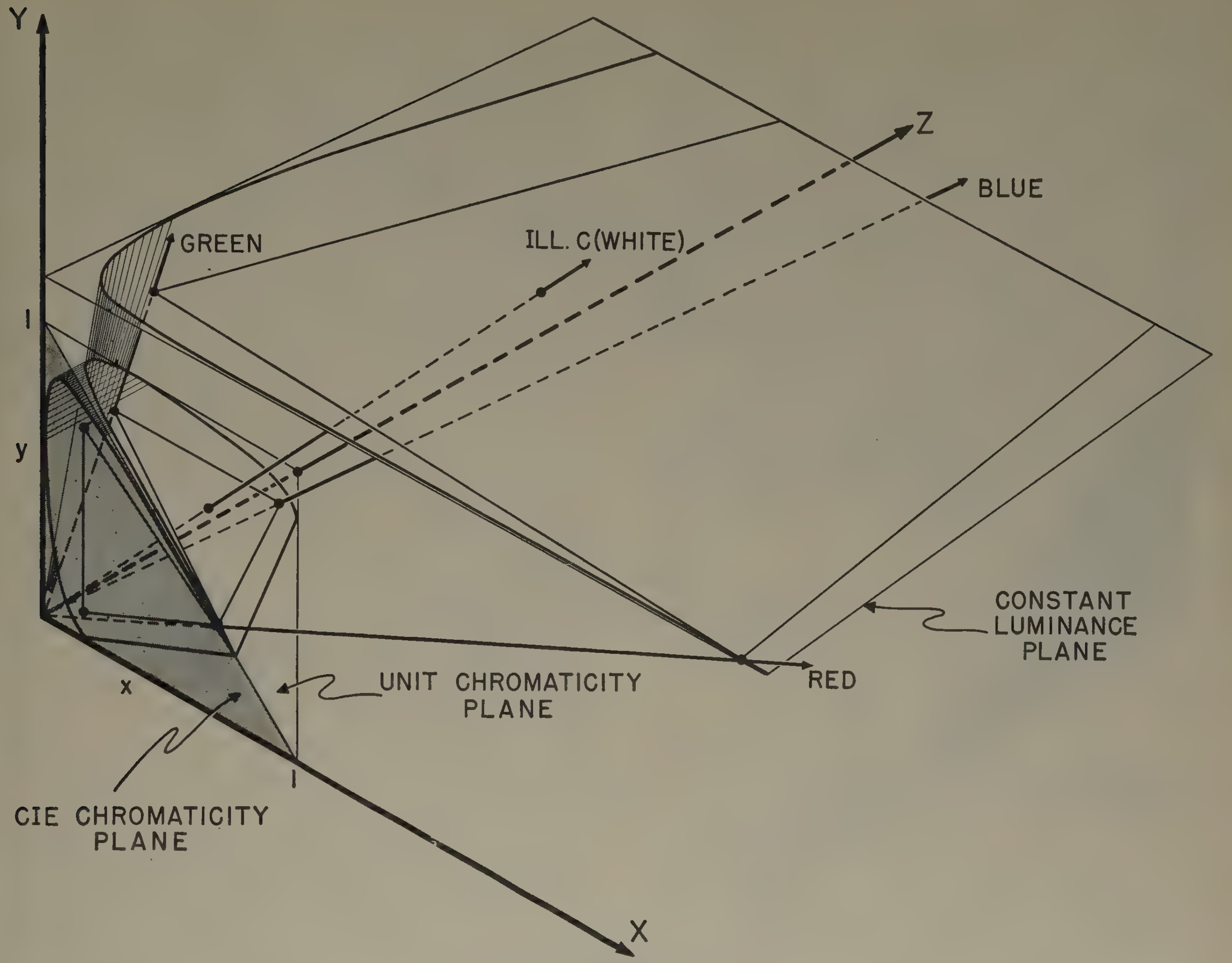

Fig. 1—CIE color space.

are non-physical. A color point may be located by giving its components along either the $(X)(Y)(Z)$ co-ordinate axes or the new set. The transformation of color data from one set of primary axes to another is simply the algebraic process of transformation of co-ordinates, the amounts of the new set of primaries being related to the amounts of the old set by three linear equations.[1]

It has been said that the transmitted signals represent the amounts of a new set of primaries, the transmission primaries. Let us see how these transmission primaries are located in the CIE color space.

Some specifications for the transmitted signals are:

(1) The monochrome signal is proportional to luminance.
(2) The two signals transmitted on the subcarrier do not affect luminance.
(3) The two signals transmitted on the subcarrier vanish when the color being transmitted is Illuminant C white.

[1] For a detailed discussion of such transformations, see W. T. Wintringham, "Color television and colorimetry," Proc. I.R.E., vol. 39, pp. 1135–1172; Oct., 1951.

Luminance Primary

Conditions (1) and (2) definitely specify that the monochrome signal controls a primary light which contributes all the luminance of the color mixture at the receiver (for this entire discussion, gamma is assumed to be unity). Condition (3) determines the chromaticity of this *monochrome*, or *luminance*, *primary*. Stated backwards, it says that when the two signals transmitted on the subcarrier are zero, the luminance primary by itself produces an Illuminant C picture. Chromaticity of the NTSC luminance primary is, therefore, that of Illuminant C, so this primary is given symbol (W) for white.

Chrominance Primaries

Condition (2) specifies that the two signals transmitted on the subcarrier control zero luminance primaries similar to (X) and (Z). These primaries, therefore, lie in the zero luminance, or XZ plane, but their chromaticity is not entirely determined by this specification. Any two co-ordinate axes lying in the XZ plane could be used. To obtain a simple pair of such primaries, it is further specified that one of them may be matched by a mixture of the red and green primaries only, while

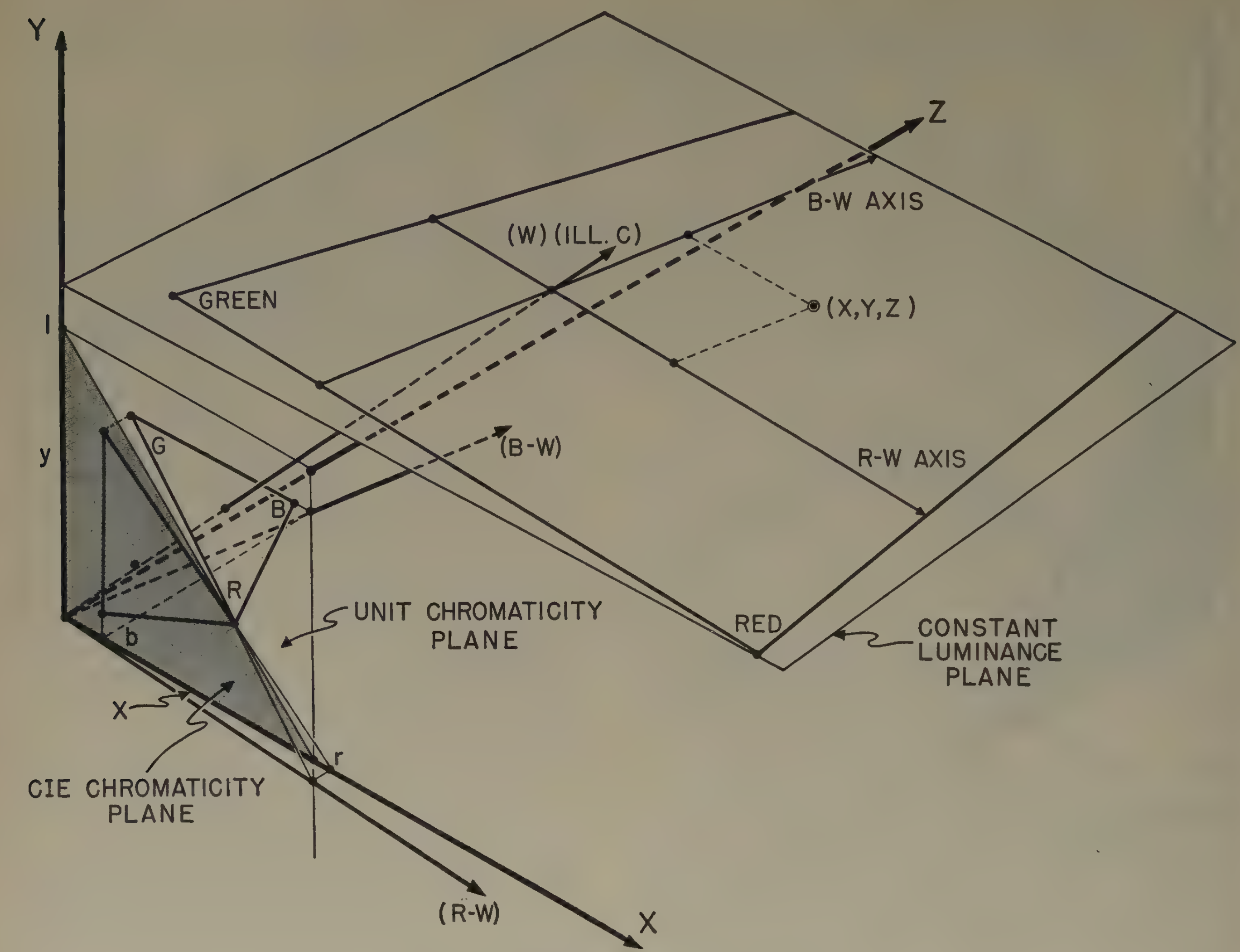

Fig. 2—NTSC primaries in CIE color space.

the other may be matched by a mixture of green and blue only. The amount of the first primary, therefore, has nothing to do with the amount of blue in the picture, while the second primary has nothing to do with the red, assuming that the luminance is fixed.

The mixture of these two zero luminance primaries produces the chrominance component of the color picture, so they may be called *chrominance primaries*. In the color space, the zero-blue chrominance primary is the line of intersection of the red-green plane with the zero luminance plane, while the zero-red primary is the intersection of the blue-green plane with the zero luminance plane. When we transform color data from the RGB set of primaries to the set of axes comprising these chrominance primaries and the luminance primary (W), the amounts of the chrominance primaries turn out to be $R-W$ for the zero-blue and $B-W$ for the zero-red chrominance primary, where W is the amount of the luminance primary and is equal to the luminance. The location of the (W), $(R-W)$ and $(B-W)$ primary axes in the CIE color space is shown in Fig. 2.

The chromaticities of the $(R-W)$ and $(B-W)$ primaries are easily determined by finding the points at which they pierce the unit plane. Note that the $(R-W)$ primary lies slightly outside the first octant of the CIE color space, so it pierces an extension of the unit plane at a value of x slightly greater than once. A little geometric reasoning will show that the chromaticity of $(R-W)$ is determined directly on the CIE chromaticity diagram by the intersection of the zero-blue (or red-green) line with the x axis. (Point r, Fig. 2.) Since both primaries lie in the zero luminance plane, y is zero.

Let us say that we are transmitting the color X, Y, Z which lies in the constant luminance plane shown in Fig. 2. The NTSC transmission primaries would be used to match this color in the following way:

The luminance primary (W) produces an Illuminant C color point of the same luminance as the point X, Y, Z. Now addition of some of the $(R-W)$ primary will move the reproduced color in the plane of constant luminance, parallel to the direction of the $(R-W)$ primary axis. Addition of the $(B-W)$ primary produces similar results, so by the addition of the proper amounts of $(R-W)$ and $(B-W)$ light (indicated by the dotted lines), the color X, Y, Z is matched by a mixture of the NTSC transmission primaries.

Fine and Coarse Chrominance Primaries

The final NTSC signal specifications require that one component of the chrominance signal be transmitted with a wider bandwidth than the other. With this arrangement, greater subjective sharpness of the color picture is obtained with the wideband component of the chrominance signal located 33° in advance of the phase of the $R-W$ subcarrier axis and with the narrow-band component 33° in advance of the $B-W$ axis. These wide and narrow-band signals represent the amounts of two new chrominance primaries: The Fine Chrominance Primary, (I), controlled by the wideband signal, and the Coarse Chrominance Primary, (Q), controlled by the narrow-band signal.

Determination of the chromaticity of the (I) and (Q) primaries involves more effort than required for the $(R-W)$, $(B-W)$ primaries. The *amounts*, I and Q, of these primaries are related to $R-W$ and $B-W$ by the 33° phase relation of their respective subcarrier axes, so the expressions for I, Q, and W in terms of R, G, and B may easily be obtained. These expressions are given in the NTSC Signal Specifications. Going further, we may obtain the expressions for I, Q, and W in terms of X, Y, and Z. Now in the $(I)(Q)(W)$ co-ordinate system, any point on the (I) axis is characterized by the fact that the *amounts* of the other two primaries are zero. Thus by setting the expressions for Q and W equal to zero, we obtain an expression for a straight line in the XZ plane; the (I) axis. The chromaticity of (I) is then determined by its intersection with the unit plane. It turns out that the direction of the (I) primary is such that it will never pierce the unit plane when extended in the positive direction, so we extend it in the negative direction and determine the chromaticity of $(-I)$. In a similar way, the (Q) axis is determined by setting I and W equal to zero.

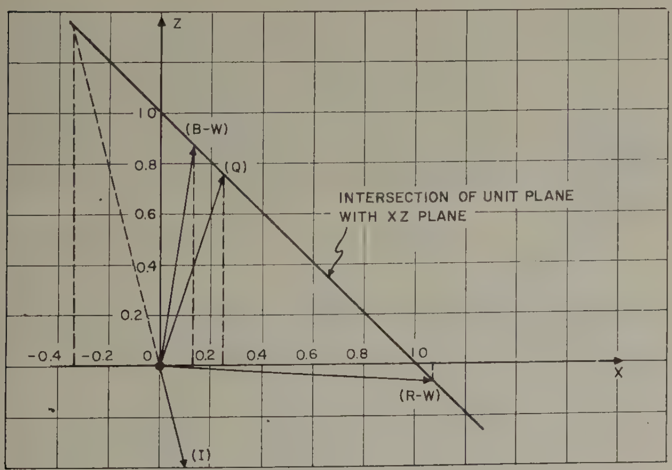

Fig. 3—Chrominance primaries in CIE XZ plane.

Fig. 3 shows the location of the $(R-W)$, $(B-W)$, and (I) and (Q) primary axes in the XZ plane, together with constructions indicating their chromaticity.

Transmission Primaries in the Chromaticity Diagram

Color mixtures in the chromaticity diagram are illustrated in Fig. 4. On this diagram are shown the (R), (G), (B) receiver primaries and the (W), $(R-W)$, $(B-W)$ transmission primaries. Color mixtures of the transmission primaries follow the usual laws. Mixtures of the $(R-W)$ and (W) primaries can produce any chromaticity on the line passing through these primaries. If we wish to produce chromaticities on the opposite side of (W) from $(R-W)$, we must use negative amounts of $(R-W)$. The lines normally indicated as $(R-W)$ and $(B-W)$ axes are, therefore, not determined by these primaries alone, but represent the results of mixtures of one of these primaries with the luminance primary. They are the sides (or extensions of the sides) of the transmission primary color triangle.

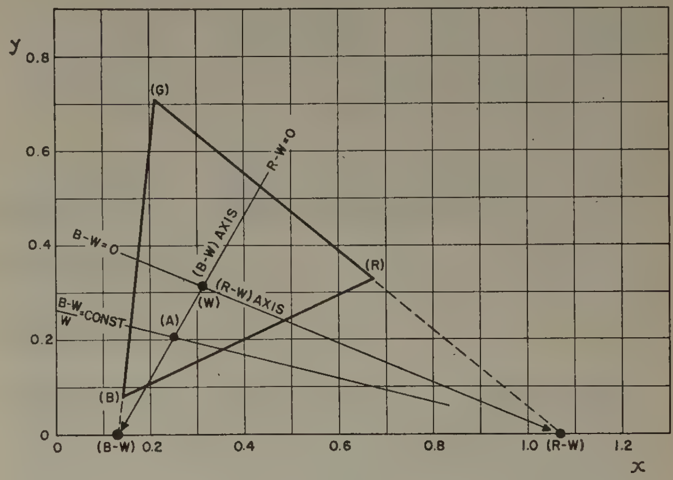

Fig. 4—NTSC transmission primaries in chromaticity diagram.

Mixtures of three primaries are obtained by an extension of this process. If a mixture of (W) and $(B-W)$ light produces the chromaticity of point (A), the addition of $(R-W)$ light can produce any chromaticity on the line joining point (A) to the $(R-W)$ primary. Positive amounts of $(R-W)$ shift the chromaticity from point (A) toward the $(R-W)$ primary, negative amounts shift it away from this primary. Since this line represents mixtures of chromaticity (A), produced by a fixed ratio of $(B-W)$ and (W) light, with different amounts of $R-W$ light, it may be called the line of constant $B-W/W$. For different values of this ratio, a set of such lines radiating from the $(R-W)$ primary may be drawn. A similar set of lines radiating from the $(B-W)$ primary would correspond to different values of $R-W/W$. The color mixture grid produced in this way was first shown by Bingley.[2]

This view of color mixtures of the transmission primaries clearly shows that the chromaticity produced at the receiver depends, not on the amounts of the chromi-

[2] F. J. Bingley, "Colorimetry in Color Television," part 3, NTSC Panel 12, Monograph #8, Proc. I.R.E., pp. 51–57, this issue.

nance primaries, but on the ratio of their amount to that of the luminance primary. Fig. 5 shows the location of the $(-I)(Q)$ and (W) primaries in the chromaticity diagram, as well as the (I) and (Q) axes. A similar grid of I/W and Q/W lines could be constructed in this diagram. It should be noted that since the $(-I)$ primary is shown, an increase in the value of I will move the chromaticity away, rather than toward, this primary.

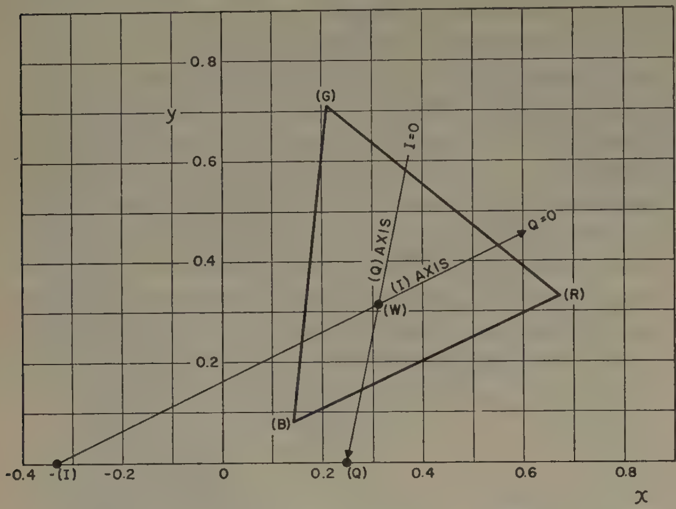

Fig. 5—NTSC transmission primaries in chromaticity diagram.

This discussion is intended to clarify some of the definitions relating to the chrominance signals, and has been entirely qualitative for this reason. For those who may wish to have quantitative data, however, the following Table of the chromaticities and luminosity coefficients of the various transmission primaries is included.

TABLE I

NTSC Transmission Primaries

Primary	Chromaticity		Luminosity Coefficient
	x	y	
(W)	.310	.316	1
$(R-W)$	1.070	0	0
$(B-W)$	.131	0	0
$-(I)$	$-.333$	0	0
(Q)	.245	0	0

Colorimetric Analysis of the NTSC Color Television System*

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Summary—**After a brief outline of the relevant colorimetric principles, a mathematical formulation is developed for use in analyzing the colorimetric properties of color television systems. The method is employed to determine properties of three different forms of the NTSC color system, one of these being the standard one. It is shown that color distortion, constant-luminance failure, and monochrome compatibility can be measured and predicted analytically.**

Introduction

THIS PAPER will develop a system of mathematical analysis which permits a detailed study of the colorimetric properties of color television systems of the general type introduced by the NTSC. Among the properties which can be studied through these means will be color fidelity, compatibility with monochrome television, and adherence to the Constant-Luminance Principle.[1]

Throughout the later stages of the development of the NTSC color system, this analytical technique has been applied repeatedly to the analysis of a number of modified forms of the system which were suggested from time to time by various NTSC affiliates. In addition to developing the method and presenting the appropriate analysis for the present NTSC system, this paper has as one of its foremost purposes the presentation of analyses for several systems which seem to be of sufficient interest to warrant documentation of their properties in spite of their not having been adopted by the NTSC.

Formulation of Analytical Method

1. *Colorimetric Principles*

A brief review of certain principles from colorimetry seems advisable before proceeding into a derivation of the analytical formulation. However, the reader will be assumed to be reasonably familiar with these principles, and the review is intended not so much to provide acquaintance with these principles as to introduce the language and notation to be employed in the later derivations.[2]

A color can be described in terms of the amounts of each of three primary colors which, when added together in a physical colorimeter, result in a color which appears to an average observer to possess similar brightness and chromaticity. If the symbols (R), (G), and (B) are used to represent unit amounts of these primaries, nominally to be called red, green, and blue, respectively, and if R, G, and B units of each are found to colormatch the given color, then the composition of that color in terms of those primaries can be represented as

$$\text{color} = R(R) + G(G) + B(B).$$

* Decimal classification: R-583. Original manuscript received by the Institute, July 15, 1953; revised manuscript received October 6, 1953.

† Sylvania Electric Products, Inc., Bayside, N. Y.

[1] W. F. Bailey, "Constant luminance principle in NTSC color television," Proc. I.R.E., pp. 60–66, this issue.

[2] W. T. Wintringham, "Color television and colorimetry," Proc. I.R.E., vol. 39, pp. 1135–1172; October, 1951, gives a more detailed outline of the colorimetric principles.

R, G, and B are called *tristimulus values* in terms of the primaries (R), (G), and (B).

In terms of the nonphysical X, Y, Z primaries, the analogous expression for the same color can be written as

$$\text{color} = X(X) + Y(Y) + Z(Z),$$

with X, Y, and Z called the tristimulus values in terms of (X), (Y), and (Z). The X, Y, Z primaries are so chosen that co-ordinate Y is a measure of the subjective brightness or *luminance* of the color. If the units (R), (G), (B) and (X), (Y), (Z) as well as the quantities R, G, B and X, Y, Z, representing numbers of units, are regarded as elements of column matrices, so that

$$C = \begin{bmatrix} R \\ G \\ B \end{bmatrix} \qquad \mathbf{C} = \begin{bmatrix} (R) \\ (G) \\ (B) \end{bmatrix}$$

and

$$W = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \qquad \mathbf{W} = \begin{bmatrix} (X) \\ (Y) \\ (Z) \end{bmatrix},$$

then there results the relation

$$\tilde{C}\mathbf{C} = \tilde{W}\mathbf{W}, \tag{1}$$

the symbol $\tilde{C}$ denoting the transpose of C.

In practice, the units $\mathbf{C}$ will be given in terms of the standard units $\mathbf{W}$. Let this relation be

$$\mathbf{C} = w_c\mathbf{W}, \tag{2}$$

in which w_c is a 3×3 transformation matrix. Substitution of (2) into (1) yields

$$C = \tilde{w}_c^{-1}W, \tag{3}$$

where $\tilde{w}_c^{-1}$ is the transposed inverse of w_c. Equation (3) relates R, G, B values to X, Y, Z values when the primary units transform according to (2).

Since the tristimulus values increase linearly with the brightness of a color of fixed chromaticity, it is convenient to normalize these to obtain quantities dependent only on chromaticity and independent of brightness. This is done by dividing the *total tristimulus value* into the component tristimulus values to obtain *trichromatic coefficients* r, g, b and x, y, z. The pertinent relations are

$$r = \frac{R}{\Sigma_c}, \quad g = \frac{G}{\Sigma_c}, \quad b = \frac{B}{\Sigma_c}, \quad \Sigma_c = R + G + B \tag{4}$$

and

$$x = \frac{X}{\Sigma_w}, \quad y = \frac{Y}{\Sigma_w}, \quad z = \frac{Z}{\Sigma_w}, \quad \Sigma_w = X + Y + Z. \tag{5}$$

It is obvious from these relations that

$$r + g + b = x + y + z = 1. \tag{6}$$

The primary units are usually chosen in such a way that $\Sigma_c = \Sigma_w$, but this is not necessary. When the units are so chosen, the single symbol Σ can be used to represent both Σ_c and Σ_w.

2. *Properties of the Camera*

The color television camera, indicated symbolically at the extreme left in Fig. 1, contains three color receptors, each having a different spectral sensitivity. These produce electrical signals which are delivered either directly or in linear combination to three camera output terminals. The camera will be considered to deliver output signals approximately proportional to the tristimulus values of the scene being scanned, the tristimulus values being those in terms of the receiver primaries. The latter are to be assumed, following the recommendation of NTSC Panel 7, to be given by

	x	y
red	.67	.33
green	.21	.71
blue	.14	.08,

from which it follows from (2) that

$$\begin{bmatrix} (R) \\ (G) \\ (B) \end{bmatrix} = \begin{bmatrix} .67 & .33 & .00 \\ .21 & .71 & .08 \\ .14 & .08 & .78 \end{bmatrix} \begin{bmatrix} (X) \\ (Y) \\ (Z) \end{bmatrix}$$

if the units are adjusted in size so that $\Sigma_c = \Sigma_w \equiv \Sigma$.

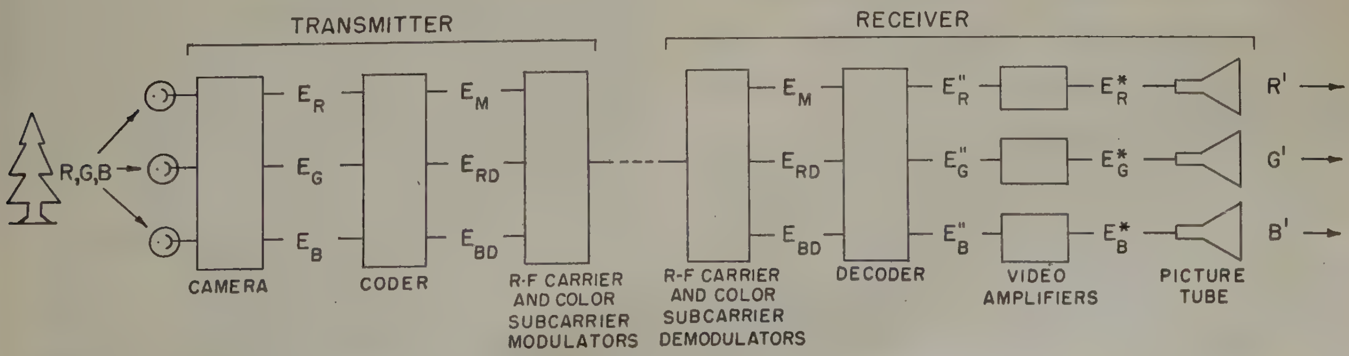

Fig. 1—Block diagram of NTSC color television system in a generalized form.

Then, from (3),

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} .67 & .33 & .00 \\ .21 & .71 & .08 \\ .14 & .14 & .78 \end{bmatrix}^{-1} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

$$= \begin{bmatrix} 1.730 & -.482 & -.261 \\ -.812 & 1.649 & -.0234 \\ .0833 & -.169 & 1.284 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}. \quad (7)$$

It has also been recommended that the color subcarrier be arranged to vanish when the light before the camera has the color of Illuminant C. It will prove useful, in this connection, to know the relative magnitudes of R, G, and B corresponding to Illuminant C. These may be found by (7) and the fact that Illuminant C has trichromatic coefficients $x=.310$ and $y=.316$, so that

$$\begin{bmatrix} r \\ g \\ b \end{bmatrix} = \begin{bmatrix} 1.730 & -.482 & -.261 \\ -.812 & 1.649 & -.0234 \\ .0833 & -.169 & 1.284 \end{bmatrix} \begin{bmatrix} .310 \\ .316 \\ .374 \end{bmatrix}$$

$$= \begin{bmatrix} .286 \\ .261 \\ .453 \end{bmatrix}. \quad (8)$$

Equation (8) was obtained from (7) by dividing through both sides by $\Sigma_c = \Sigma_w$ to convert from tristimulus values to trichromatic coefficients, the coefficients for Illuminant C then being inserted and the matrix multiplication carried out.

The assumed linearity between light values and camera-signal voltage outputs will permit the latter to be expressed in terms of R, G, and B as

$$E_R = k_R R \qquad E_G = k_G G \qquad E_B = k_B B, \quad (9)$$

k_R, k_G, and k_B being constants. It will be convenient to arrange that $E_R = E_G = E_B = \Sigma$ when the color before the camera is Illuminant C, i.e., when

$$\frac{R}{.286} = \frac{G}{.261} = \frac{B}{.453} = \Sigma, \quad (10)$$

as follows from (4) and (8). This converts (9) into

$$R = .286E_R \quad G = .261E_G \quad B = .453E_B, \quad (11)$$

which completely establishes the colorimetric properties of the camera.

Equation (11) is representative of an ideal, distortionless camera. Although it is possible in principle to construct a camera whose properties conform rigorously to (11), most cameras in actual use do no more than provide an approximation to this response. Principles underlying the design of a colorimetrically distortionless camera must be considered beyond scope of this paper.

3. *Properties of the Color Picture Tube*

Just as relations have been established between the light input and the signal-voltage output of the camera, it is necessary to deduce expressions describing the light output of the color picture tube in terms of the signal voltage to it. Picture tubes are observed to possess power-law responses of the form

$$Y = aE^{\gamma}$$

over a wide range of signal voltages. E is the grid drive voltage, measured with respect to cutoff, and Y is the screen brightness. a and γ are constants. The value of γ generally lies in the range 2.0–2.4, the median being 2.2.

Present purposes will be served by writing

$$R' = a_R E_R^{*\gamma} \quad G' = a_G E_G^{*\gamma} \quad B' = a_B E_B^{*\gamma} \quad (12)$$

for the responses of the red, green, and blue picture-tube channels, respectively. R', G', B' here represent the tristimulus values of the light output from the-picture tube. a_R, a_G, a_B are the sensitivities of the picture-tube channels, generally differing in value from one channel to another. E_R^*, E_G^*, E_B^* are the grid-drive voltages of the various channels.

In all color television systems to be considered here, these drive voltages will be representable in terms of voltages E_R'', E_G'', E_B'' at other points in the color television receiver through relations of the form

$$E_R^* = n^{1/\gamma} n_R^{1/\gamma} E_R'' \qquad E_G^* = n^{1/\gamma} n_G^{1/\gamma} E_G'' \qquad E_B^* = n^{1/\gamma} n_B^{1/\gamma} E_B''. \quad (13)$$

$n_R^{1/\gamma}$, $n_G^{1/\gamma}$, $n_B^{1/\gamma}$ are to be regarded as relative voltage gains of video amplifiers immediately preceding the picture tube as indicated at the extreme right in Fig. 1, and $n^{1/\gamma}$ is a separate gain factor the product of which with each relative gain gives the corresponding absolute voltage gain. Thus, E_R'', E_G'', E_B'' are input voltages to the video amplifiers whose output terminals are the signal voltage terminals of the picture tube. In practice, the parameter $n^{1/\gamma}$ expresses the effect of a contrast control which is arranged to raise or lower the signals to all channels in equal proportions so that the picture contrast varies without change in color balance.

Now substituting (13) in (12), one finds

$$R' = nn_R a_R E_R''^{\gamma} \qquad G' = nn_G a_G E_G''^{\gamma} \qquad B' = nn_B a_B E_B''^{\gamma} \quad (14)$$

for the light output from the picture tube. In the ideal case, the voltages E_R'', E_G'', E_B'' would be exactly the voltages $E_R^{1/\gamma}$, $E_G^{1/\gamma}$, $E_B^{1/\gamma}$, and it would be desirable that the light outputs R', G', B' would then be proportional to R, G, B. Letting the proportionality constant be the quantity n introduced earlier, and requiring the receiver to exhibit the ideal response when the color before the camera is Illuminant C, the conditions are

$$R' = nR = .286n\Sigma$$
$$G' = nG = .261n\Sigma$$
$$B' = nB = .453n\Sigma$$

and

$$E_R''^{\gamma} = E_R = \Sigma$$
$$E_G''^{\gamma} = E_G = \Sigma$$
$$E_B''^{\gamma} = E_B = \Sigma$$

to be satisfied simultaneously. Substituting these into (14) yields

$$\frac{n_R a_R}{.286} = \frac{n_G a_G}{.261} = \frac{n_B a_B}{.453} = 1. \qquad (15)$$

Equation (15) states the manner in which the video amplifier relative gains must be related to the picture tube sensitivities in order that the picture tube will reproduce Illuminant C when this color is before the camera.

Finally, substitution of (15) into (14) gives

$$R' = .286nE_R''^{\gamma} \qquad G' = .261nE_G''^{\gamma} \qquad B' = .453nE_B''^{\gamma} \qquad (16)$$

as the expressions for the colorimetric output from the picture tube. It remains to relate E_R'', E_G'', E_B'' to the tristimulus values R, G, B of the color before the camera. For distortionless reproduction of all colors within the gamut of the picture tube, it is necessary that E_R'', E_G'', $E_B''=E_R^{1/\gamma}$, $E_G^{1/\gamma}$, $E_B^{1/\gamma}$ over the entire gamut.[3] To determine whether this can be done, it will be necessary to consider the portion of the color television system between the camera output terminals and the receiver video amplifier input terminals.

4. *Properties of the Complete System*

The section of the transmitter which transforms the video signals E_R, E_G, E_B from the camera into signals suitable for modulation onto the RF carrier and the color subcarrier will be called the *coder*. The corresponding section of the receiver which attempts to recover the gamma-corrected signals $E_R^{1/\gamma}$, $E_G^{1/\gamma}$, $E_B^{1/\gamma}$ from the demodulator output signals will be called the *decoder*. The positions of the coder and decoder in the system are shown in Fig. 1. The NTSC system can be regarded as one whose coder translates the video signals into a *monochrome signal* E_M and a pair of *color-difference signals* E_{RD} *and* E_{BD}. If the picture tube response were linear, it would be satisfactory to use for E_M a signal proportional to the luminance Y of the original scene and for the color-difference signals the forms $E_{RD}=E_R-E_M$ and $E_{BD}=E_B-E_M$. Then the receiver signals E_R'' and E_B'' could be produced by adding together the monochrome and color-difference signals:

$$E_R'' = E_{RD} + E_M = (E_R - E_M) + E_M = E_R$$
$$E_B'' = E_{BD} + E_M = (E_B - E_M) + E_M = E_B.$$

If E_M was a linear combination of E_R, E_G, E_B, then the green color-difference signal E_{GD} could be formed by combining E_{RD} and E_{BD} in the proper proportions, and E_G could then be obtained by adding E_M to E_{GD}. This will be demonstrated later for a more general case than the linear system.

Since picture tubes are not linear, it is necessary to employ "gamma-correction." If the correction is applied at the transmitter, as seems desirable on the basis of economic considerations and noise sensitivity of the receiver, it is necessary to modify either the monochrome signal or the color-difference signals or both in such a way that, upon recovery at the receiver, they can be converted into $E_R^{1/\gamma}$, $E_G^{1/\gamma}$, $E_B^{1/\gamma}$ to as close an approximation as possible.

The most satisfactory means for gamma-correcting is not immediately apparent, nor is it safe to suppose the best means to be that which leads to perfect color reproduction. For, as is well-known, there are considerations other than fidelity of color reproduction which can be expected to be of importance in evaluating the merits of a color television system. Moreover, since the camera itself is not usually capable of producing precisely the proper color signals for all colors, a rigorously correct method of gamma-correction still will not insure complete color fidelity. Finally, the eye itself is incapable of discerning color errors below a certain minimum level.

In view of these facts, it will not be sufficient merely to develop means for predicting the color fidelity of a system. It will also be necessary to be able to predict other important properties as well. Foremost among these are the susceptibility of the system to noise and interference and the suitability of the broadcast signals for eliciting from a conventional monochrome receiver the proper luminance irrespective of the color before the camera. These ends will be served by the definition of several quantities, to be called *system parameters*, which will be expressible numerically through appropriate formulas derived from the preceding colorimetric theory.

Before defining the system parameters, it will be worth while to consider the derivation of the monochrome signal in terms of the colorimetric quantities. The monochrome signal E_M in a linear system should be directly proportional to the luminance Y of the scene being scanned. That is, E_M should be given by

$$E_M = \beta Y, \qquad (17)$$

β being a constant. Now (7) gives

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} .67 & .21 & .14 \\ .33 & .71 & .08 \\ .00 & .08 & .78 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix},$$

from which

$$Y = .33R + .71G + .08B. \qquad (18)$$

Introducing (11) and (18) into (17) gives

$$E_M = \beta[.33(.286)E_R + .71(.261)E_G + .08(.453)E_B]. \qquad (19)$$

[3] The notation $A, B, C=a, b, c$ will be used as a shorthand equivalent of the three equations $A=a$, $B=b$, $C=c$.

In the interest of compatibility with monochrome television, E_{RD} and E_{BD} are required to vanish at Illuminant C. Since E_R, E_G, E_B have already been arranged to equal Σ at Illuminant C, E_M must also assume this value in order to allow E_{RD} and E_{BD} to vanish. This condition determines the value of β in (19), whence

$$E_M = .299E_R + .587E_G + .114E_B, \tag{20}$$

which is the form usually given for the monochrome signal in a linear system. Present purposes will require that this be given in terms of R, G, and B. This is obtained by substituting (11) into (20), the result being

$$E_M = \frac{.299}{.286}R + \frac{.587}{.261}G + \frac{.114}{.453}B. \tag{21}$$

Finally, another useful form, to be called the ***normalized monochrome signal*** e_M is to be defined in such a way as to replace R, G, B by r, g, b, thus making e_M uniquely determined at each value of r, g, b whereas E_M can have any value whatever. In the linear case, e_M is defined as

$$e_M \equiv \frac{E_M}{\Sigma} = \frac{.299}{.286}r + \frac{.587}{.261}g + \frac{.114}{.453}b, \tag{22}$$

wherein use has been made of (4).

It will now be convenient to proceed with definitions and derivation of formulas for the system parameters.

5. The System Parameters

Two quantities, a vector and a scalar, will be defined for describing the color response of a color television system. The *Chromatic Distortion Vector* Δc with components $\Delta r = r' - r$, $\Delta g = g' - g$, and $\Delta b = b' - b$ will measure changes in chromaticity. Actually, only two components need be calculated, since (6) results in the condition $\Delta r + \Delta g + \Delta b = 0$.

The components of Δc can be plotted on a chromaticity diagram as arrows of such length and direction as to indicate directly the nature of the chromatic distortion. In the present form of the gamma-corrected NTSC system, it will be found that $\Delta r = \Delta g = \Delta b = 0$ for all colors, signifying that there is no chromatic distortion present.

The second color-response parameter will be called the *Luminance Fidelity F*. It will be defined as the ratio of the actual reproduced luminance on a color receiver to n times the luminance of the original scene, or

$$F \equiv \frac{Y'}{nY} = \frac{1}{n}\,\frac{.33R' + .71G' + .08B'}{.33R + .71G + .08B}. \tag{23}$$

A frequently more useful form for F follows directly from (23) and (4). It is

$$F = \frac{.33\dfrac{R'}{n\Sigma} + .71\dfrac{G'}{n\Sigma} + .08\dfrac{B'}{n\Sigma}}{.33r + .71g + .08b}. \tag{24}$$

This form is convenient for use since $R'/n\Sigma$, $G'/n\Sigma$, $B'/n\Sigma$ are readily calculable in terms of r, g, b as will be demonstrated later.

As a measure of the degree of adherence of a system to the Constant-Luminance Principle, the *Constant-Luminance Index K* will be defined. This will be the ratio of the portion of the reproduced luminance on a color receiver due to the monochrome signal to the total reproduced luminance due to both the monochrome and color-difference signals. The total reproduced luminance is

$$Y' = .33R' + .71G' + .08B',$$

which, upon using (16), becomes

$$Y' = n[.33(.286)E_R''^{\gamma} + .71(.261)E_G''^{\gamma} + .08(.453)E_B''^{\gamma}]. \tag{25}$$

If E_R'', E_G'', $E_B'' = E_{RD} + E_M$, $E_{GD} + E_M$, $E_{BD} + E_M$, as is the case in the linear form and in the present form of the NTSC system, then

$$Y' = n[.33(.286)(E_{RD} + E_M)^{\gamma} + .71(.261)(E_{GD} + E_M)^{\gamma} + .08(.453)(E_{BD} + E_M)^{\gamma}] \tag{26}$$

is the final expression for the displayed luminance. The portion Y_M' of this due to the monochrome signal alone is found by placing $E_{RD} = E_{GD} = E_{BD} = 0$ in (26); thus,

$$Y_M' = .316nE_M^{\gamma}. \tag{27}$$

The Constant-Luminance Index $K \equiv Y_M'/Y'$ then becomes

$$K = \frac{E_M^{\gamma}}{.299(E_{RD} + E_M)^{\gamma} + .587(E_{GD} + E_M)^{\gamma} + .114(E_{BD} + E_M)^{\gamma}}. \tag{28}$$

It is desirable that K be as nearly unity as possible for all colors producible by the picture tube.

The final system parameter to be introduced in the present section is the *Monochrome Luminance Fidelity* F_m, defined as the ratio of reproduced luminance Y_{Mm}' on a conventional monochrome receiver in response to the monochrome signal E_M to n times the original luminance, or $F_m \equiv Y_{Mm}'/nY$. In the form of system under consideration, it is evident that $Y_{Mm}' = Y_M'$. Hence,

$$F_m = \frac{Y_M'}{nY} = \frac{Y_M'}{Y'} \cdot \frac{Y'}{nY} = KF, \tag{29}$$

so that F_m is deducible from K and F. F_m, incidentally, is identical with the Chromaticity Factor K_C introduced by Applebaum.[4]

The Present NTSC System

The foregoing analytical techniques will now be applied to the study of several forms which have been considered for the NTSC color television system. The study will begin with the form of the system utilizing the currently adopted NTSC signal standards. The signals are

$$E_M = .299E_R^{1/\gamma} + .587E_G^{1/\gamma} + .114E_B^{1/\gamma} \equiv E_Y' \tag{30}$$

$$E_{RD} = E_R^{1/\gamma} - E_M \tag{31}$$

$$E_{BD} = E_B^{1/\gamma} - E_M, \tag{32}$$

with E_{GD} obtainable by linear combination of E_{RD} and E_{GD}:

$$E_{GD} = -\frac{.299}{.587}E_{RD} - \frac{.114}{.587}E_{BD}. \tag{33}$$

The conventional NTSC receiver forms the video-amplifier input signals E_R'', E_G'', $E_B'' = E_R^{1/\gamma}$, $E_G^{1/\gamma}$, $E_B^{1/\gamma}$ by addition of E_{RD}, E_{GD}, E_{BD}, respectively, to the monochrome signal E_M. It then quickly follows from (11) and (16) that

$$R' = nR \qquad G' = nG \qquad B' = nB. \tag{34}$$

The trichromatic coefficients r', g', b' of the reproduced color are then found through use of (4) to be

$$r' = r \qquad g' = g \qquad b' = b.$$

Thus, the components Δr, Δg, Δb of the Chromatic Distortion Vector are all zero, indicating that there is no chromatic distortion.

The Luminance Fidelity F is identically unity, as is seen by substitution of (34) into (23). Thus, not only is there no chromatic distortion; there is also no luminance distortion.

Next to be considered are K and F_m, which are the same in this case as is seen from (29) with $F=1$. From (28) and the relations E_R'', E_G'', $E_B'' = E_R^{1/\gamma}$, $E_G^{1/\gamma}$, $E_B^{1/\gamma}$,

$$K = \frac{(.299E_R^{1/\gamma} + .587E_G^{1/\gamma} + .114E_B^{1/\gamma})^\gamma}{.299E_R + .587E_G + .114E_B}.$$

Introduction of (4) and (11) gives

$$K = \frac{\left[\frac{.299}{(.286)^{1/\gamma}} r^{1/\gamma} + \frac{.587}{(.261)^{1/\gamma}} g^{1/\gamma} + \frac{.114}{(.453)^{1/\gamma}} b^{1/\gamma}\right]^\gamma}{\frac{.299}{.286} r + \frac{.587}{.261} g + \frac{.114}{.453} b} \tag{35}$$

as the expression for the Constant-Luminance Index as a function of the trichromatic coefficients of the color before the camera. Using the value $\gamma = 2.2$ for the gamma exponent in accordance with the present NTSC signal specification, (35) yields contours of constant K as shown in Fig. 2. Since $K = F_m$ for this case, Fig. 2 also represents contours of constant F_m.

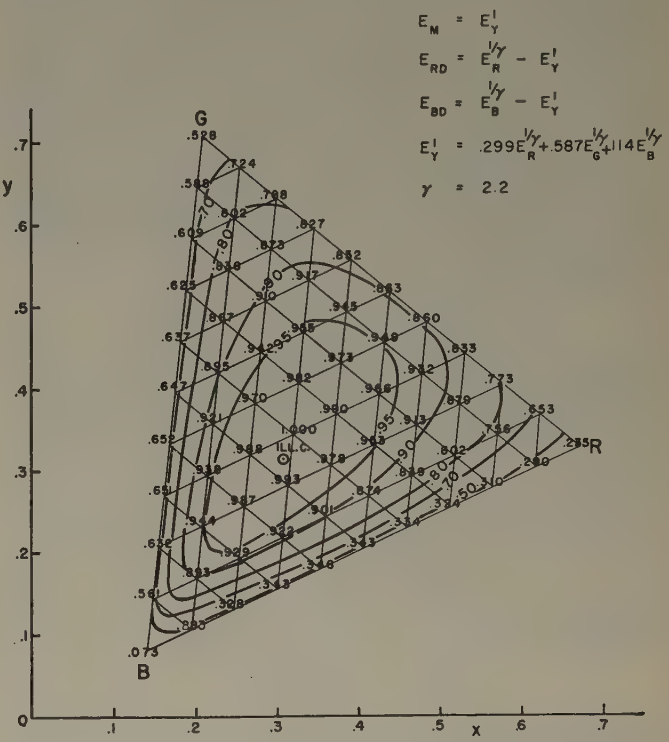

Fig. 2—Constant-luminance index K and monochrome luminance fidelity F_m in system using signals as indicated.

It is seen that constant-luminance failure occurs in increasing degrees at colors of increasing saturation, the effect being fairly sizable at red and becoming quite severe at blue. Similarly, it is seen that monochrome receivers will exhibit too little brightness when saturated colors are being observed. It is for the purpose of alleviating these defects in the present system that the other systems next to be studied were conceived.

Some Factors Influencing System Performance

It is next to be enquired whether the signals can be so modified as to result in increased values for the parameters K and F_m without at the same time introducing a prohibitive amount of color distortion; this will require some examination of the factors which govern the performance of a color system of the NTSC type.

The most important requirement is the attainment of acceptable color fidelity. This means that, to a fairly good approximation, the receiver decoder output signals E_R'', E_G'', E_B'' must be $E_R^{1/\gamma}$, $E_G^{1/\gamma}$, $E_B^{1/\gamma}$. Small departures, of course, might be tolerable. The decoder circuitry should be simple and preferably linear. If, as in the conventional NTSC receiver, the signals E_R'', E_G'', E_B'' are formed by adding the monochrome

[4] S. Applebaum, "Gamma correction in constant luminance color television systems," Proc. I.R.E., vol. 40, pp. 1185–1195; October, 1952.

signal E_M to color-difference signals E_{RD}, E_{GD}, E_{BD}, then the latter evidently must be of the forms

$$E_{RD} = E_R^{1/\gamma} - E_D \qquad E_{GD} = E_G^{1/\gamma} - E_D \qquad E_{BD} = E_B^{1/\gamma} - E_D, \tag{36}$$

with E_D not differing appreciably from E_M. Now E_{RD} and E_{BD} can be transmitted by being modulated at quadrature to each other on a subcarrier, but this leaves no means for transmitting E_{GD}. The way usually used to avert this difficulty is to so construct E_{RD}, E_{GD}, E_{BD} that E_{GD} is a linear combination of E_{RD} and E_{BD}, thus making possible the formation of E_{GD} in the receiver by combining E_{RD} and E_{BD} in the proper proportions. It is readily established that this condition of linear dependence between the color-difference signals restricts E_D to the form

$$E_D = \epsilon_R R_R^{1/\gamma} + \epsilon_G E_G^{1/\gamma} + \epsilon_B E_B^{1/\gamma}, \tag{37}$$

wherein ϵ_R, ϵ_G, ϵ_B are constants which sum to unity. For full color fidelity, it follows that E_M must also have the form in (37). If E_M differs from E_D, the decoder being operated as before, the decoder output signals will be

$$E_R'' = E_R^{1/\gamma} + E_{MD} \qquad E_G'' = E_G^{1/\gamma} + E_{MD} \qquad E_B'' = E_B^{1/\gamma} + E_{MD}, \tag{38}$$

in which

$$E_{MD} = E_M - E_D. \tag{39}$$

Unless E_{MD} is quite small, appreciable color distortion will result. This is unfortunate inasmuch as it would be desirable to use

$$E_Y^{1/\gamma} = (.299E_R + .587E_G + .114E_B)^{1/\gamma} \tag{40}$$

for the monochrome signal E_M in order to transmit in the luminance channel the full luminance to be reproduced, thus aiming toward adherence to the Constant-Luminance Principle. Moreover, this signal would give complete monochrome luminance fidelity; i.e., F_m would be unity. Actually, K would not become identically unity even if $E_M = E_Y^{1/\gamma}$; for the effect of the quantity E_{MD} would be to modify the displayed luminance by a certain amount, thereby causing a departure from the desired value. Thus, from the monochrome signal would come exactly the desired luminance, while the color-difference signals would add or subtract a certain amount of luminance.

This seems to be an unresolvable dilemma, and a compromise between color fidelity and the other desirable characteristics appears to be required. The philosophy to be employed might be to explore the possibilities for varying the forms of the monochrome signal E_M and the subtractive signal E_D in such a manner that K and F_m are increased toward unity as much as possible while E_{MD} is kept as small as possible. A method by which this might be accomplished will be analyzed shortly.

It will prove convenient to introduce ***normalized*** quantities at this point, these quantities being functions only of chromaticity and independent of total tristimulus value or luminance. This will be accomplished simply by dividing by Σ^n when the form for the quantity is linear in R^n, G^n, B^n. Thus, (4), (10), (11), (30), and (40) lead to the following relations:

$$e_R = \frac{E_R}{\Sigma} \qquad e_G = \frac{E_G}{\Sigma} \qquad e_B = \frac{E_B}{\Sigma}. \tag{41}$$

$$r = .286e_R \qquad g = .261e_G \qquad b = .453e_B \tag{42}$$

$$e_Y' = \frac{.299}{(.286)^{1/\gamma}} r^{1/\gamma} + \frac{.587}{(.261)^{1/\gamma}} g^{1/\gamma} + \frac{.114}{(.453)} b^{1/\gamma} \tag{43}$$

$$e_Y^{1/\gamma} = \left(\frac{.299}{.286} r + \frac{.587}{.261} g + \frac{.114}{.453} b\right)^{1/\gamma}. \tag{44}$$

The general formulas

$$e_M = \frac{E_M}{\Sigma^{1/\gamma}} \qquad e_D = \frac{E_D}{\Sigma^{1/\gamma}} \qquad e_{MD} = \frac{E_{MD}}{\Sigma^{1/\gamma}} \tag{45}$$

and

$$e_{RD} = \frac{E_{RD}}{\Sigma^{1/\gamma}} \qquad e_{GD} = \frac{E_{GD}}{\Sigma^{1/\gamma}} \qquad e_{BD} = \frac{E_{BD}}{\Sigma^{1/\gamma}} \tag{46}$$

are also available. These quantities will lend themselves to being plotted on chromaticity diagrams, whereas the unnormalized quantities cannot be so plotted.

Properties of System in Which $E_M = E_Y^{1/\gamma}$

It has been seen that correct color reproduction by an NTSC-type receiver requires that E_M and E_D be the same and given by (37), although an appreciable amount of constant-luminance failure will be encountered under these conditions. It was also noted that $F_m = 1$ could be achieved and the values for K increased by using $E_M = E_Y^{1/\gamma}$, but a conventional NTSC color receiver using these signals would also show color distortion.

It is instructive to examine this $E_Y^{1/\gamma}$ system to determine whether the color distortion is large enough to be serious and whether the improvement in constant-luminance adherence is appreciable.

The first consideration must be to keep E_{MD} in (39) as small as possible. This suggests choosing ϵ_R, ϵ_G, ϵ_B so that

$$\frac{\partial E_{MD}}{\partial E_R} = \frac{\partial E_{MD}}{\partial E_G} = \frac{\partial E_{MD}}{\partial E_B} = 0$$

is satisfied at Illuminant C, where $E_{MD} = 0$. This condition yields ϵ_R, ϵ_G, $\epsilon_B = .299$, .587, .114, so that $E_D = E_Y'$. Equation (38) then shows the decoder-output signals from an NTSC receiver to be

$$E_R'' = E_R^{1/\gamma} - \Delta E_Y \qquad E_G'' = E_G^{1/\gamma} - \Delta E_Y \qquad E_B'' = E_B^{1/\gamma} - \Delta E_Y, \tag{47}$$

with

$$\Delta E_Y \equiv E_Y^{1/\gamma} - E_Y'. \tag{48}$$

Equations (4), (11), (16), and (47) thereupon give

$$\frac{R'}{n\Sigma} = [r^{1/\gamma} + (.286)^{1/\gamma}\Delta e_Y]^\gamma \tag{49a}$$

$$\frac{G'}{n\Sigma} = [g^{1/\gamma} + (.261)^{1/\gamma}\Delta e_Y]^\gamma \tag{49b}$$

$$\frac{B'}{n\Sigma} = [b^{1/\gamma} + (.453)^{1/\gamma}\Delta e_Y]^\gamma, \tag{49c}$$

wherein $\Delta e_Y \equiv \Delta E_Y/\Sigma^{1/\gamma}$. Upon introduction of $\Sigma' = R'+G'+B'$, the trichromatic coefficients of the new color become

$$r' = \frac{n\Sigma}{\Sigma'}[r^{1/\gamma} + (.286)^{1/\gamma}\Delta e_Y]^\gamma \tag{50a}$$

$$g' = \frac{n\Sigma}{\Sigma'}[g^{1/\gamma} + (.261)^{1/\gamma}\Delta e_Y]^\gamma \tag{50b}$$

$$b' = \frac{n\Sigma}{\Sigma'}[b^{1/\gamma} + (.453)^{1/\gamma}\Delta e_Y]^\gamma. \tag{50c}$$

The Chromatic Distortion Components $\Delta r, \Delta g, \Delta b$ are thus found for any given r, g, b values by substitution of (50) into

$$\Delta r = r' - r \qquad \Delta g = g' - g \qquad \Delta b = b' - b. \tag{51}$$

Values found in this way at[5] $r, g, b = 0$ (.1) 1.0 are shown on a chromaticity diagram as a chromatic distortion map in Fig. 3. Each arrow or short line represents the error between original and reproduced chromaticity, original chromaticities being at $r, g, b = 0$ (.1) 1.0 points.

It is to be observed that the chromatic distortion is quite small everywhere except along the $r=0$ edge in the range $.5 < g < 1.0$ and along the $g=0$ edge in the range $.5 < r < 1.0$, and that the distortions in both of these areas are primarily in the direction of the blue primary. These are precisely the areas in which the eye is least able to discern distortion toward blue; and it might be expected that these chromatic distortions, although relatively large, would be relatively inconspicuous in a color television display. It is to be concluded that the chromatic distortion inherent in this system might not be objectionable.

To determine the error in reproduction of luminance, one must evaluate the Luminance Fidelity F, given by (24), using in it the values of $R'/n\Sigma$, $G'/n\Sigma$, $B'/n\Sigma$ given in (49). The resulting map of F over the receiver gamut appears in Fig. 4. It is seen that the correct luminance is reproduced at Illuminant C, but that it is everywhere else too large. The areas of greatest excess are not only the areas in which the chromatic errors were greatest, but also some areas where very little chromatic error was present. Thus, at $r, g, b = 0.4, 0, 0.6$ in Fig. 3 is seen almost zero chromatic distortion while the reproduced luminance at this same point is seen in Fig. 4 to be 1.72 times the proper value.

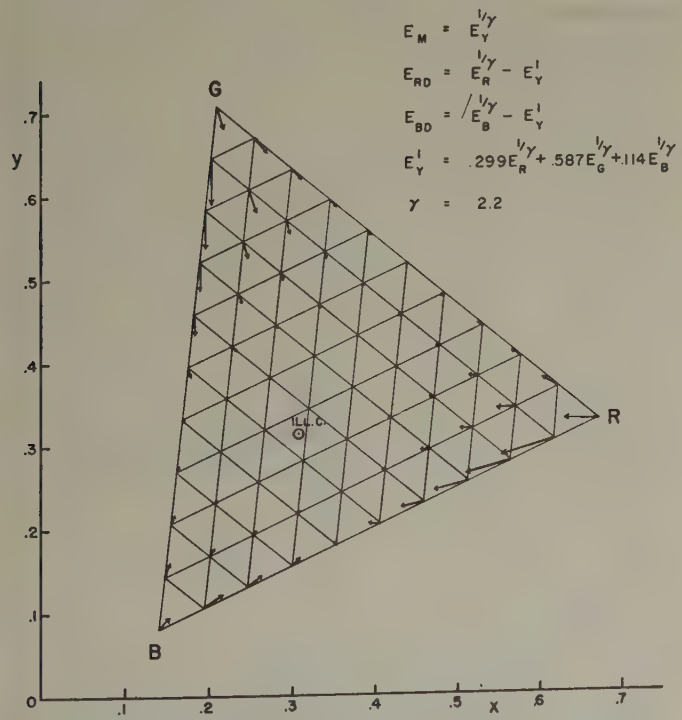

Fig. 3—Chromatic distortion in system using signals as indicated.

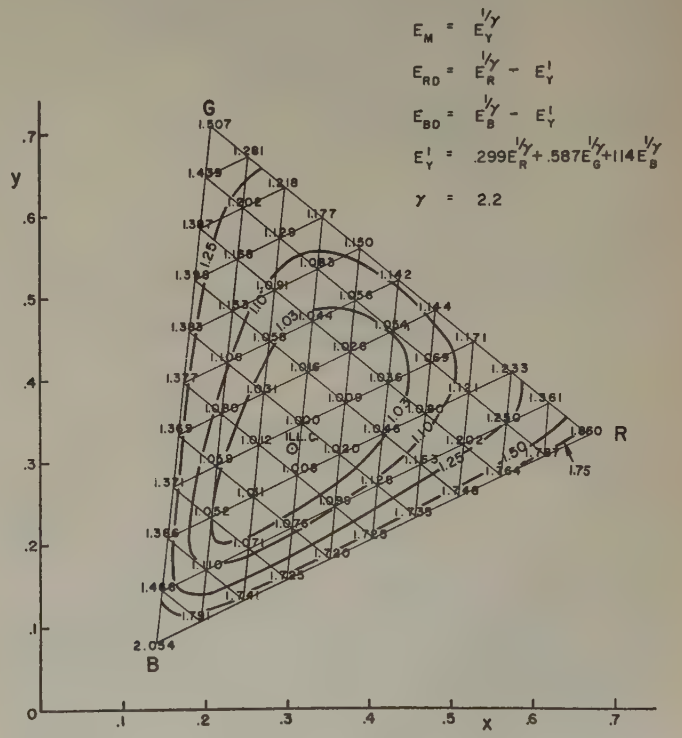

Fig. 4—Luminance fidelity F in system using signals as indicated.

Next to be considered is the performance of the $E_Y^{1/\gamma}$ system with respect to constant-luminance. Substitution of (36) into (28) and normalizing yields

[5] The notation $r, g, b = 0$ (.1) 1.0 will be used as a shorthand way of writing $r = 0$ (.1) 1.0, $g = 0$ (.1) 1.0, $b = 0$ (.1) 1.0. The notation $r = 0(.1)$ 1.0 is a conventional way of signifying that r assumes successively, by increments of 0.1, the values from 0 to 0.1.

$$K = \frac{\frac{.299}{.286} r + \frac{.587}{.261} g + \frac{.114}{.453} b}{\frac{.299}{.286} [r^{1/\gamma} + (.286)^{1/\gamma}\Delta e_Y]^\gamma + \frac{.587}{.261} [g^{1/\gamma} + (.261)^{1/\gamma}\Delta e_Y]^\gamma + \frac{.114}{.453} [b^{1/\gamma} + (.453)^{1/\gamma}\Delta e_Y]^\gamma}. \quad (52)$$

In Fig. 5 is given a map of K over the receiver gamut. Comparison with Fig. 2 shows that K has been greatly improved in the areas where improvement is most urgently needed, although further improvement is greatly to be desired.

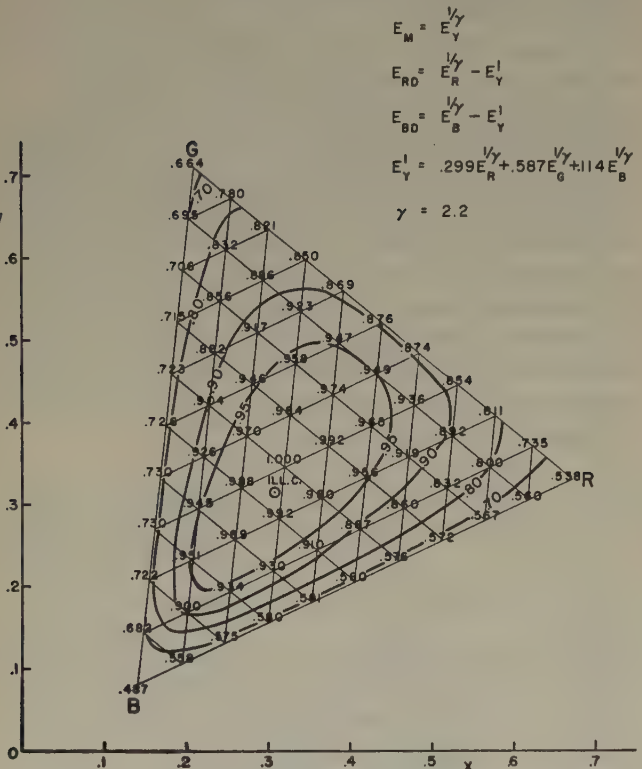

Fig. 5—Constant-luminance index K in system using signals as indicated.

The suitability of the monochrome signal $E_M = E_Y^{1/\gamma}$ for obtaining proper luminance reproduction from a conventional monochrome receiver has already been noted. The Monochrome Luminance Fidelity F_m is identically unity over the receiver gamut. With this observation, analysis of the $E_Y^{1/\gamma}$ system is complete. To summarize, it has been seen that the E_Y' system,[6] although yielding correct color reproduction, exhibited relatively large constant-luminance failure and monochrome luminance error. The $E_Y^{1/\gamma}$ system, on the other hand, exhibits a certain amount of color error together with somewhat improved constant-luminance adherence and complete monochrome luminance fidelity.

[6] The present NTSC system, with $E_M = E_Y'$, will be referred to hereafter as the E_Y' system.

The Circular Subcarrier

Next to be analyzed is a type of system recently described in a paper prepared for NTSC Panel 13 by the Hazeltine Corporation.[7] The distinguishing feature of this type of system is its utilization of the so-called "circular subcarrier" arrangement and the "luminance corrector." It will be shown that the resulting system, at the cost of relatively complicated circuitry in the receiver, achieves a higher degree of constant-luminance adherence than does either the E_Y' system or the $E_Y^{1/\gamma}$ system. Furthermore, the color fidelity in this system is superior to that in the $E_Y^{1/\gamma}$ system although, of course, it cannot be better than that in the E_Y' system.

The luminance corrector will be discussed in the next section. The present section will be concerned only with the theory of the circular subcarrier, which must be employed if the full benefit of the luminance corrector is to be realized. Although one derivation for the form of the circular subcarrier was given in the Hazeltine paper,[7] a derivation will also be given here. This will serve as a convenient means for introducing the notation to be employed in the analysis of the system using the luminance corrector. Moreover, the development to be given here differs in some significant respects from that in the Hazeltine paper.

Consider a receiver in which the gamma-corrected color signals $E_R^{1/\gamma}$, $E_G^{1/\gamma}$, $E_B^{1/\gamma}$ are to be recovered from color-difference signals E_{RD}, E_{GD}, E_{BD} by adding to them a decoding signal E_0 which, as far as possible, is equal to the subtractive signal E_D used in forming the color-difference signals. The latter are assumed to be of the form in (36), with E_D as in (37). The constants ϵ_R, ϵ_G, ϵ_B are required to sum to unity but for the moment are not otherwise restricted. The form of the decoding signal will be determined later; in both the E_Y' system and the $E_Y^{1/\gamma}$ system it is identically the monochrome signal E_M, but this will not be the case in the luminance-corrector system.

Whatever the decoding signal used, the displayed luminance will be given by (25), which will now be rewritten as

$$Y' = .316n[.299E_R''^\gamma + .587E_G''^\gamma + .114E_B''^\gamma], \quad (53)$$

E_R'', E_G'', E_B'' being the decoder output signals, desired to be $E_R^{1/\gamma}$, $E_G^{1/\gamma}$, $E_B^{1/\gamma}$. Introducing the decoding signal E_0 into (53), and dividing through by this signal, gives as follows

[7] Hazeltine Corporation, "Proposal for Modification of Complete Color Signal to Provide Improved Constant-Luminance Transmission," prepared for NTSC Panel 13; July 21, 1952.

$$\frac{Y'}{E_0^\gamma} = .316n\left\{.299\left[1+\frac{E_{RD}}{E_0}\right]^\gamma + .587\left[1+\frac{E_{GD}}{E_0}\right]^\gamma + .114\left[1+\frac{E_{BD}}{E_0}\right]^\gamma\right\}. \quad (54)$$

Now the three binomials in (54) can be expanded in accordance with the binomial theorem at all chromaticities for which the absolute value of the second term in each binomial is less than unity. It will be convenient to examine this matter in detail later; at present, the binomial expansions will be executed on the understanding that results obtained thereby will be applicable only at chromaticities for which the above conditions are satisfied. Upon expansion, (54) becomes

$$\frac{Y'}{E_0^\gamma} = .316n\left\{1+\gamma\frac{.299E_{RD}+.587E_{GD}+.114E_{BD}}{E_0} + \frac{\gamma(\gamma-1)}{2}\,\frac{.299E_{RD}^2+.587E_{GD}^2+.114E_{BD}^2}{E_0^2} + \cdots\right\}. \quad (55)$$

It is desired, now, to render the displayed luminance Y' independent of subcarrier phase,[8] the accomplishment of this aim being required for optimum operation of the luminance corrector, as will be seen later. To begin, it is to be noted that E_0, in order to not differ too much from E_M, which is obviously independent of subcarrier phase, must also be independent of it. This means that the entire left-hand member of (55) is to be rendered phase-independent, whereupon, it follows that the entire right-hand side of the equation must also be so arranged. Then, since E_{RD}, E_{GD}, E_{BD} are all linear functions of subcarrier amplitude E, the series in (55) can be regarded as a power series in the independent variable E. It is then evident that each term in the series must be phase-independent if the sum of the series is to be independent of the subcarrier phase.

The term which is linear in E will be phase-independent if

$$.299E_{RD} + .587E_{GD} + .114E_{BD} \equiv M \quad (56)$$

is phase-independent. Evidently, M can be made phase-independent quite readily. For (36) and (37), with ϵ_R, ϵ_G, ϵ_B summing to unity, easily yield

$$\epsilon_R E_{RD} + \epsilon_G E_{GD} + \epsilon_B E_{BD} = 0, \quad (57)$$

so that M will vanish if ϵ_R, ϵ_G, ϵ_B, whose numerical values to this point have remained unassigned, are chosen to be .299, .587, .114, respectively. In fact, to make M phase-independent when E_{RD}, E_{GD}, E_{BD} are functions of phase and are interrelated by (54), these values *must* be assigned.

[8] It is this characteristic to which the circular subcarrier owes its name. For a color system using such a subcarrier, a polar plot of displayed luminance against subcarrier phase for various subcarrier amplitudes would be a family of circles concentric with the origin.

Turning now to the second-power term in (55), it will be convenient to introduce the relations

$$E_{RD} = m_R E\cos(\theta_R - \phi) \quad (58a)$$
$$E_{GD} = m_G E\cos(\theta_G - \phi) \quad (58b)$$
$$E_{BD} = m_B E\cos(\theta_B - \phi), \quad (58c)$$

in which m_R, m_G, m_B are constant gain factors and θ_G, θ_G, θ_B are constant "demodulation angles." E and ϕ are subcarrier amplitude and relative phase, respectively. θ_R, θ_G, θ_B and ϕ are measured with respect to a reference phase which is arbitrarily chosen so that $\theta_B = 0$. When (58) are substituted into the second-power term in (55), the condition in order that this term shall be independent of ϕ is seen to be that the derivative of

$$.299m_R^2\cos^2(\theta_R-\phi) + .587m_G^2\cos^2(\theta_G-\phi) + .114m_B^2\cos^2\phi \equiv Q \quad (59)$$

with respect to ϕ shall vanish identically for all values of ϕ. Differentiating (59) and equating the result to zero yields an expression containing two terms each of which must vanish independently of the other; thus, (59) yields two new equations.

Substituting (58) into (57) with ϵ_R, ϵ_G, $\epsilon_B = .299$, .587, .114 also yields a result resolvable into two terms each of which is required to vanish separately. Thus, in all, four equations are obtained; the independent parameters in these are m_R, m_G, m_B, θ_R, and θ_G. By suitable manipulation, these can be solved for m_R/m_B, m_G/m_B, θ_R, and θ_B, leaving m_B arbitrary. The solutions are

$$\frac{m_R}{m_B} = \frac{.114(1-.299)}{.299(1-.114)} = 0.549 \quad (60a)$$

$$\theta_R = \cos^{-1}\left(-\frac{.114}{1-.114}\,\frac{m_B}{m_R}\right) = 103.6 \text{ degrees} \quad (60b)$$

$$\theta_G = \cot^{-1}\left[\cot\theta_R + \frac{.114}{.299}\,\frac{1}{\sin\theta_R}\,\frac{m_B}{m_R}\right] = 244.7 \text{ degrees} \quad (60c)$$

$$\frac{m_G}{m_B} = -\frac{.299}{.587}\,\frac{\sin\theta_R}{\sin\theta_G} = 0.301. \quad (60d)$$

The above results now permit (55) to be reduced to

$$\frac{Y'}{E_0^\gamma} = .316n\left\{1+\frac{\gamma(\gamma-1)}{2}Q_0\left(\frac{E}{E_0}\right)^2 + \cdots\right\}, \quad (61)$$

wherein

$$Q_0 = \tfrac{1}{2}[.299m_R^2 + .587m_G^2 + .114m_B^2] \quad (62)$$

is the value found for Q in (59) when it has been adjusted to be independent of ϕ. Equation (62) is obtained simply by evaluating (59) at $\phi = 0$ and $\phi = 90$ degrees, then adding these expressions together and halving the result.

It remains to consider now the validity of the assumption that was made earlier regarding the possibility of expanding the binomials in (54) by means of the binomial theorem. The expansions are valid only when the second member of each binomial is absolutely

less than unity. If $E_D = E_Y'$, as has shown to be necessary for the "circular subcarrier," and if $E_0 = E_D$, as has been shown to be required for correct color reproduction, then the conditions for convergence of the binomial expansions are

$$\left|\frac{E_R^{1/\gamma} - E_Y'}{E_Y'}\right| < 1, \qquad \left|\frac{E_G^{1/\gamma} - E_Y'}{E_Y'}\right| < 1,$$

$$\left|\frac{E_B^{1/\gamma} - E_Y'}{E_Y'}\right| < 1.$$

It is then readily seen by insertion of appropriate numerical values that these conditions are satisfied over most of the chromaticity gamut but that the ratio involving $E_R^{1/\gamma}$ becomes excessive near the red primary while that involving $E_B^{1/\gamma}$ becomes much too large near the blue primary. Thus, the "circular subcarrier" breaks down in these areas, the breakdown being moderately large near $r=1$ and very severe near $b=1$. The mathematical effect of this breakdown can be represented as a failure of Q_0 in (62) to remain constant in the areas concerned.

The Luminance Corrector

The luminance corrector is to be envisaged as a device located in the receiver to aid in producing from the received signals the decoding signal E_0 of the desired E_Y' form when the monochrome signal is $E_Y^{1/\gamma}$. The device is intended to generate a signal of the form ΔE_Y as given by (48), the desired decoding signal $E_0 = E_Y'$ then being obtainable by subtraction of the luminance-corrector output signal ΔE_Y from the monochrome signal $E_Y^{1/\gamma}$.

To begin the derivation of the luminance-corrector theory, it is noted that Y' is

$$Y' = .316n(E_Y^{1/\gamma})^\gamma \tag{63}$$

if the chrominance signal does not contribute to it, this following directly from the principles established earlier. When (63) is introduced into (61) and when E_0 is replaced with E_Y' to express the effect of the luminance corrector, (61) becomes

$$E_Y^{1/\gamma} \cong E_Y'\left\{1 + \frac{\gamma(\gamma-1)}{2} Q_0\left(\frac{E}{E_Y'}\right)^2\right\}^{1/\gamma}. \tag{64}$$

The binominal in (64) can be expanded if the second term is absolutely less than unity. This condition is certainly satisfied near Illuminant C, where $E=0$, and it can therefore be expected to be satisfied over some region around Illuminant C, possibly excluding the neighborhoods of the saturated primaries where, however, Q_0 is not constant anyway. When the expansion is made, it is found to yield

$$\Delta E_Y \cong \frac{\gamma-1}{2} Q_0 \frac{E^2}{E_Y'}, \tag{65}$$

this being approximate because of the rejection of higher-order terms. Now E^2 is a quantity which might be obtained electronically without too great difficulty in a receiver, but E_Y' would not be available in the system under consideration. However, $E_Y^{1/\gamma}$ is available as the monochrome signal, so it is possible to design an electronic circuit to produce a signal having the form

$$\Delta E_Y^0 = \frac{\gamma-1}{2} Q_0 \frac{E^2}{E_Y^{1/\gamma}}. \tag{66}$$

Such a circuit is called a "luminance corrector." The symbol ΔE_Y^0 is intended to indicate that this quantity is only an approximation to ΔE_Y as given in (48).

In answer to any question regarding the necessity for using the circular subcarrier to achieve the full benefit of the luminance corrector, it should be noted that Q_0 in (66) is a constant only by virtue of the properties of the circular subcarrier. If the latter is not used, then Q_0 must be replaced with Q, for which no means of electrical generation in the receiver seems to be available.

Colorimetric Analysis of System Using Circular Subcarrier and Luminance Corrector

The remainder of this paper will be devoted to deriving the colorimetric properties of a color television system utilizing the circular subcarrier and the luminance corrector. In view of the fact that a considerable amount of labor is involved in the computation of the numerical values for the system parameters for this case, and since these computations were carried out at a time when the NTSC standards were based on a value of $\gamma = 2.75$ for the gamma exponent, it will be necessary to present only the analysis for a system using this old value for the exponent. In order to provide a basis for comparing this system with those not using circular subcarriers and luminance correctors, it will be necessary to furnish diagrams corresponding to Figs. 2, 3, 4, and 5 but calculated for $\gamma = 2.75$. These appear as Figs. 6, 7, 8, and 9, respectively.

The decoder-output signals in the receiver with luminance corrector are each the result of adding the monochrome signal $E_Y^{1/\gamma}$ to one of the color-difference signals in (36) with $E_D = E_Y'$ and then subtracting the luminance-corrector signal ΔE_Y^0 given in (66). Thus, one finds the following

$$E_R'' = E_R^{1/\gamma} + \Delta E_Y - \Delta E_Y^0 \tag{67a}$$

$$E_G'' = E_G^{1/\gamma} + \Delta E_Y - \Delta E_Y^0 \tag{67b}$$

$$E_B'' = E_B^{1/\gamma} + \Delta E_Y - \Delta E_Y^0, \tag{67c}$$

with ΔE_Y given by (48). It is clear that the desired E_R'', E_G'', $E_B'' = E_R^{1/\gamma}$, $E_G^{1/\gamma}$, $E_B^{1/\gamma}$ will be approached as the condition $\Delta E_Y^0 = \Delta E_Y$ is more nearly satisfied.

Evidently, it is now necessary to evaluate ΔE_Y^0 as a function of chromaticity co-ordinates r, g, b. Q_0 and $E_Y^{1/\gamma}$ in (66) are no problems, being given by previous formulas in this paper. The squared amplitude E^2 of the subcarrier is expressible as

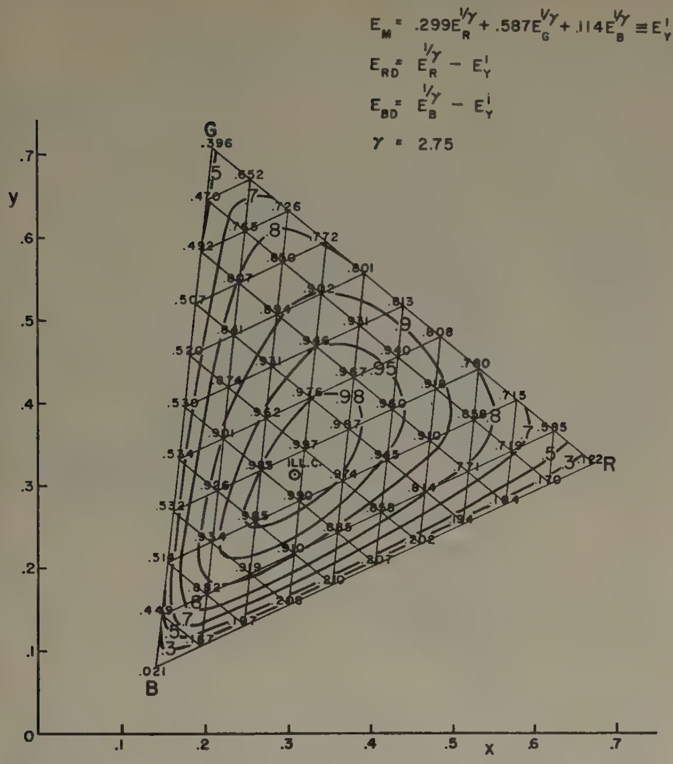

Fig. 6—Constant-luminance index K and monochrome luminance fidelity F_m in system using signals as indicated.

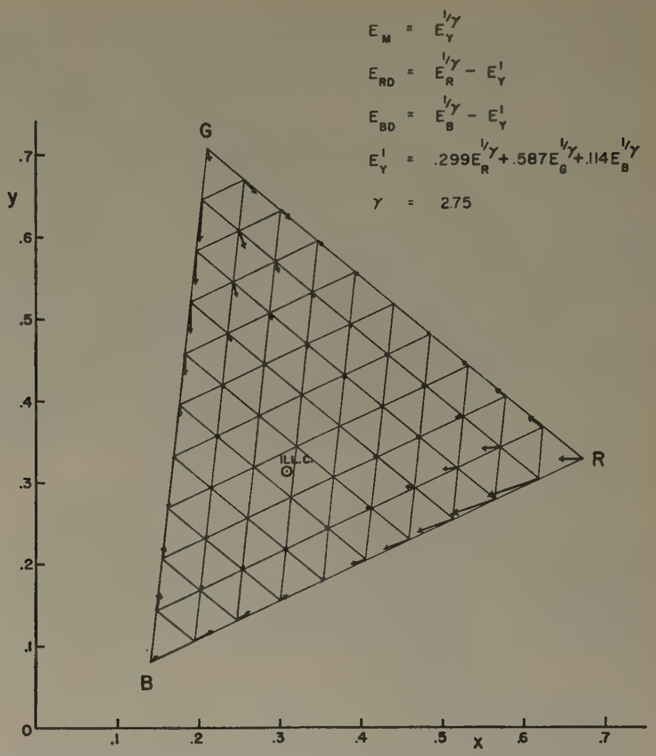

Fig. 7—Chromatic distortion in system using signals as indicated.

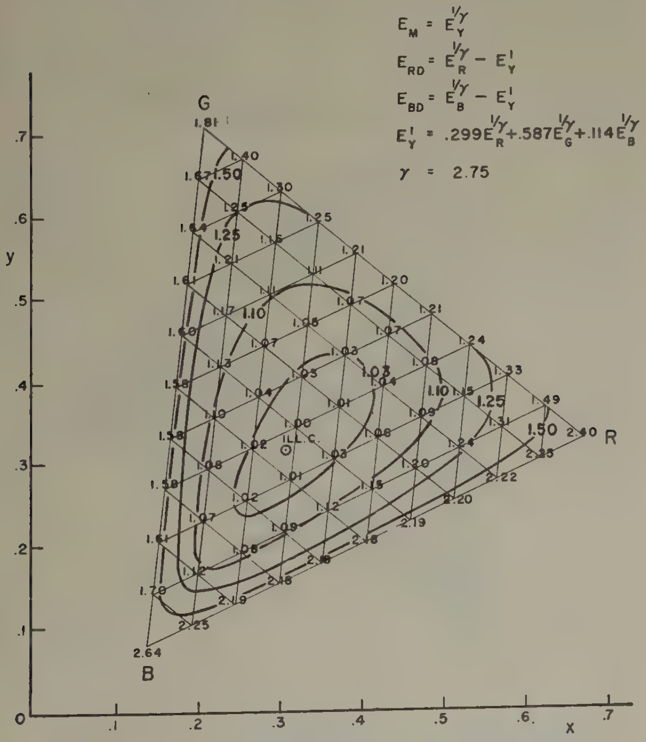

Fig. 8—Luminance fidelity F in system using signals as indicated.

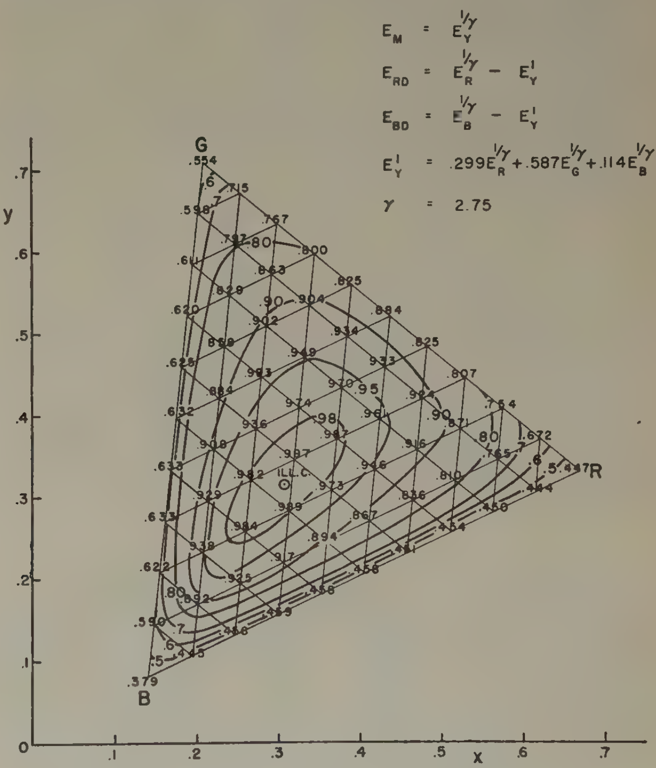

Fig. 9—Constant-luminance index K in system using signals as indicated.

$$E^2 = E_P{}^2 + E_N{}^2, \tag{68}$$

in which E_P and E_N are components of the subcarrier at quadrature to each other. In particular, E_P and E_N will be taken to be the components with relative phases $\phi = 0$ and $\phi = 90$ degrees, respectively. Through considerations based on the foregoing theory of the circular subcarrier, it is readily ascertained that

$$E_P = \frac{E_{BD}}{m_B}$$

$$E_N = \frac{E_{BD}}{m_B} \tan \phi_B + \frac{E_{RD}}{m_R} \sec (\phi_R - \theta_R). \tag{69}$$

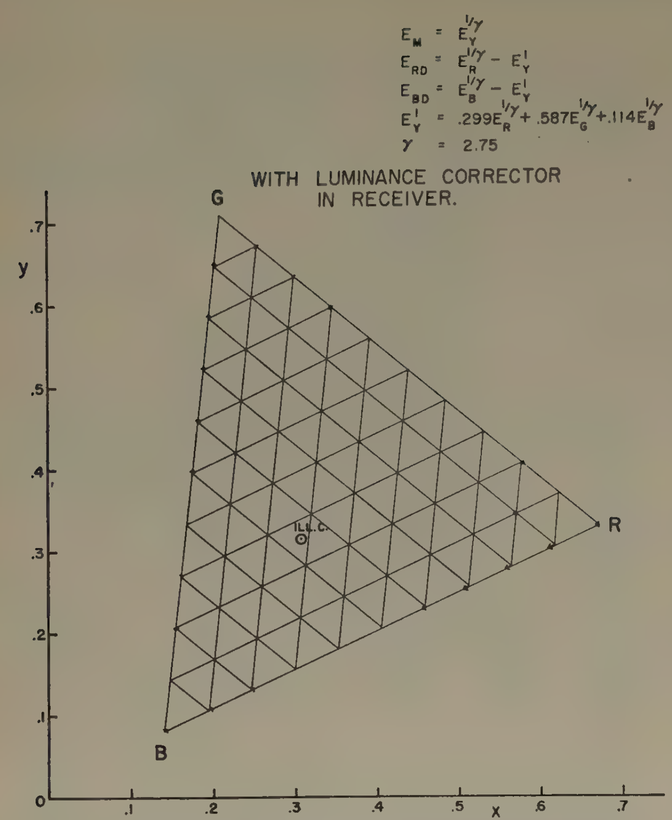

Fig. 10—Chromatic distortion in system using signals as indicated.

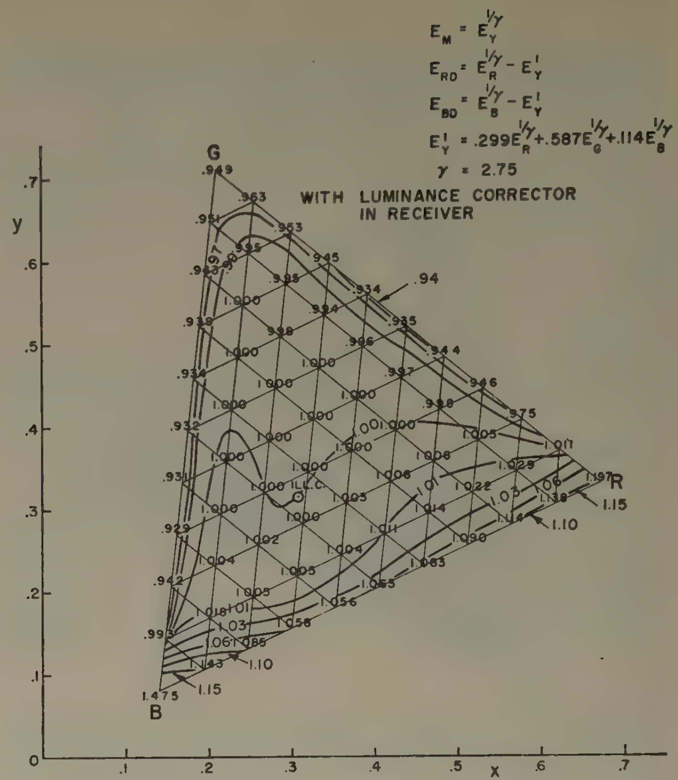

Fig. 11—Luminance fidelity F in system using signals as indicated.

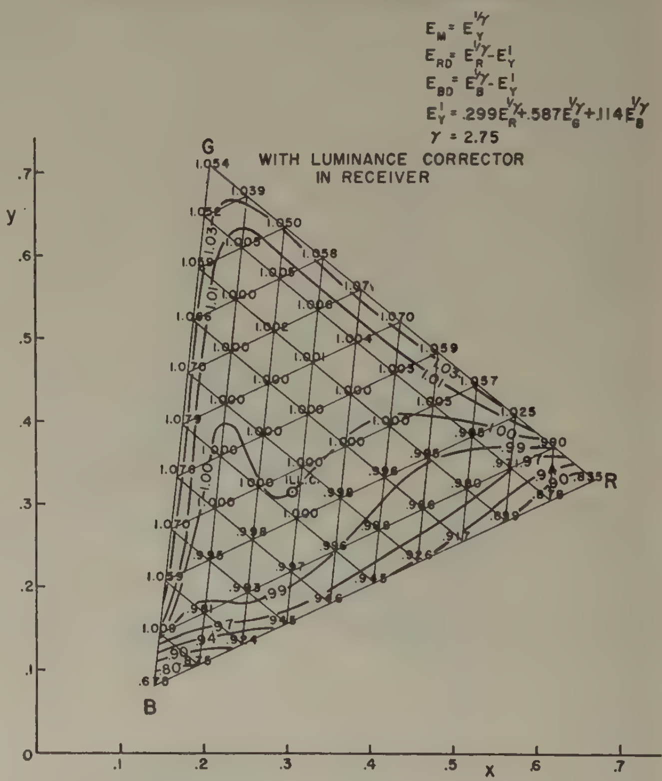

Fig. 12—Constant-luminance index K in system using signals as indicated.

When m_R is arbitrarily assigned the value 2.03, which is its value for the standard NTSC subcarrier, and when ϕ_B, ϕ_R, θ_R, and m_R are as found earlier in this paper, (69) gives

$$E_P = \frac{E_{BD}}{2.03} \qquad E_N = \frac{E_{BD}}{8.44} + \frac{E_{RD}}{1.08}. \tag{70}$$

The techniques developed earlier are now directly applicable to the analysis of the luminance-corrector system. The procedures are the same as before and need not be repeated in detail. The results are shown in Figs. 10, 11, and 12. The Monochrome Luminance Fidelity, being identically unity, is not plotted.

Conclusions

It has been demonstrated that the theory of physical colorimetry can be applied to the NTSC color television system to reveal important information on the inherent abilities of the basic system and of variant forms thereof to display faithful reproductions of colored scenes. Information is also made available on the degree to which the transmitted color signals are able to elicit from a monochrome receiver a picture whose luminance values correspond to those in the original scene. Finally, information is also provided on the extent to which the performance of the color system departs from the Constant-Luminance Principle.

By means of the foregoing methods it has been found practical to perform analytical studies of various color systems and to deduce their relative merits. Moreover, through the extension of the basic theory by introducing other system parameters as occasion arises, the method has proved itself a powerful tool in the investigation of properties of the systems other than those treated in the present paper. Space does not permit discussion of these refinements in this paper.

Quantitative Spectral Measurements in Color Television*

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Summary—Techniques for spectral and colorimetric measurement of a color television system are described. Two measurements are needed to determine whether the transducers will perform as desired in the NTSC system: first, the spectral taking sensitivities of the color cameras or pickup devices and second, the colorimetric characteristics of the display devices. The techniques to be described herein make use of narrow-band optical interference filters used in conjunction with certain "red pass" gelatin filters. Reasonably accurate measurements are obtained from which the colorimetric characteristics of the transducers can be calculated and the over-all color performance determined.

Introduction

THE ADDITION of color to the television art introduces new problems in television engineering. One of these problems is the quantitative measurement of color. The rules governing color and color mixture are rather well established in the empirical science of colorimetry. Standard techniques of spectral and colorimetric measurement which are directly applicable to color television are not so firmly established.

Two general types of light measurements are needed in a color television system. The first of these is a determination of the spectral taking sensitivities of the color cameras. The second is a determination of the colorimetric co-ordinates of the tricolor display primaries.

There are several techniques for measuring camera taking sensitivities and display primaries. One method of measuring the taking sensitivities involves calibrated monochromatic light sources. These sources are, in general, inconvenient and expensive. The measurement of display primaries can be done by measuring their spectral distributions and then calculating their colorimetric co-ordinates or by simply measuring their colorimetric co-ordinates directly. Spectral measurements may involve the use of some type of spectrophotometer employing either a prism or a diffraction grating. These devices are quite expensive, they usually need intense sources of illumination and they are sensitive to jarring and moving. Direct colorimetric measurements with the ordinary types of colorimeters are very simple to make but their accuracy often depends upon the operator or is limited in some other way.

The purpose of this paper is to discuss a method for making these measurements by using narrow-band optical interference filters and other associated equipment. A somewhat similar method of measuring taking sensitivities has been described.[1] The method described herein results in reasonably accurate spectral measurements from which colorimetric co-ordinates can be calculated when desired. The problems of mechanical stability are reduced and the intensity of illuminants to be measured can be quite low.

Filters

The filters employed in this investigation are actually combinations of narrow-band optical filters and selected red pass Wratten filters. All of these are commercially available. The narrow-band filters are manufactured by the Bausch and Lomb Optical Company and by the Farrand Optical Company. The Wratten gelatin filters are manufactured by the Eastman Kodak Company.

Transmission type interference filters consist of two highly reflecting but partially transmitting films of silver separated by a spacer film of non-absorbing material. The result of this combination is an interference effect which produces high transmission when the spacing of the silver films is an odd multiple of a half wavelength. All of the narrow-band filters used in this work were second-order filters, that is, their pass band in the visible spectrum is actually the second harmonic of their fundamental mode. As an example, a filter that has a peak transmission wavelength of 500 millimicrons in the visible spectrum will have its fundamental peak transmission wavelength at one micron. It will also have a considerable transmission at its third-mode wavelength of 333 millimicrons. Some of the filters also have a small pass band in the region of 320 millimicrons regardless of the wavelength of the fundamental mode. For filters in the visible spectrum, the fundamental mode is of no consequence because the photoelectric cell sensitivity is extremely low in the infrared region.

It is the third mode falling in the violet and ultraviolet region that makes it necessary to use red-pass filters in conjunction with the narrow-band interference filters because most photoelectric cells are extremely sensitive to ultraviolet light and the short-wavelength end of the visible spectrum. The Wratten filters also suppress the spurious fixed pass band around 320 millimicrons in those filters where it occurs. Table I gives a list of the narrow-band interference filters used in our work and the Wratten filters that were used with them. It must be remembered that these

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[1] R. C. Moore, J. F. Fisher and J. B. Chatten, "Measurement and control of the color characteristics of a flying-spot color signal generator," PROC. I.R.E., vol. 41, pp. 730–733; June, 1953.

Wrattens were selected for the individual narrow-band filters that were used, and would have to be individually selected and their transmission factors checked when used with other interference filters even of the same type.

Alternative techniques for eliminating undesirable modes have been used successfully by other investigators. Appropriate Corning glass filters may be used instead of Wratten gelatin filters. Another technique is to use two narrow-band optical filters in cascade. One filter will have the same wavelength for its first order mode as the second filter has for its second order mode. In this manner there will be only one narrow band of wavelengths in the spectrum for which light can pass through both filters simultaneously. This latter technique is probably the most satisfactory although it is more expensive. Furthermore, it allows a smaller total transmission of light, since the peak transmission of interference filters is only about 30 to 35 per cent, so that the two in tandem may only pass 10 per cent or less of the incident light.

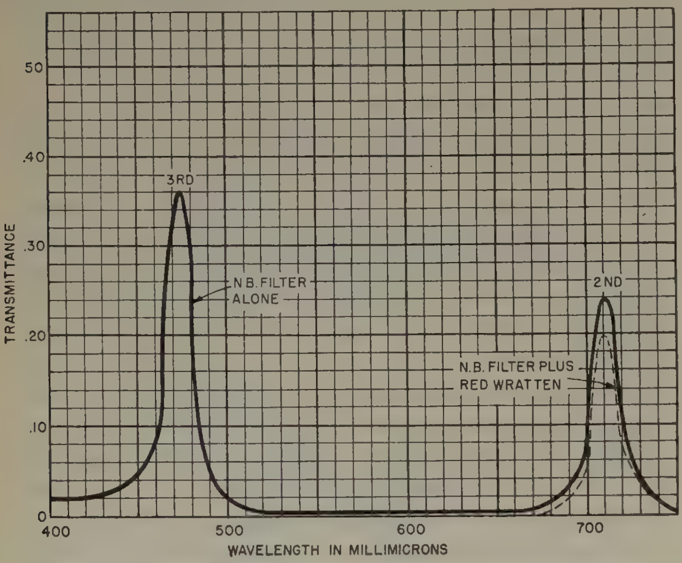

Fig. 1—Typical transmittance of a narrow-band filter plus Wratten filter.

In their second-order mode, the interference filters have a half-power bandwidth of about 10 millimicrons. Below the half-power points the transmission characteristics broaden considerably but the error introduced by this broadening is small. A typical transmission curve for a narrow-band optical filter is given in Fig. 1. For the filter calibrations to be accurate, the light through them must be collimated, and must enter the filter within 2 degrees of normal. Fig. 2 shows curves of peak transmission vs. angle of incidence.

Determination of Taking Sensitivities

The correct colorimetric representation of any point in a scene can be expressed by a set of three tristimulus values. These three values can be linearly matrixed to other sets of values also containing all the information needed for a correct colorimetric representation. One such set of tristimulus values are the CIE values X, Y, and Z from which the co-ordinates x and y can be determined in the CIE co-ordinate system.

In a color television system, three cameras are used to obtain a time sequence of instantaneous signals proportional to the tristimulus values of the viewed scene.

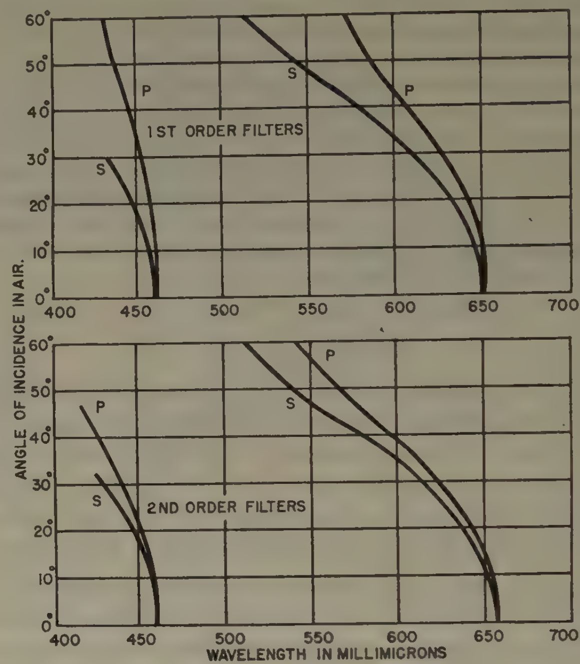

Fig. 2—Wavelength shift with angle of incidence. P—polarized in the plane of incidence. S—polarized perpendicular to the plane of incidence.

If the camera spectral responses have the proper shape, the camera will deliver electrical signals which can then be matrixed to obtain the desired set of tristimulus values. We shall use, for convenience, the CIE values X, Y, and Z in our spectral measurements. If C_1, C_2, C_3 are the respective spectral responses of the three cameras and F_1, F_2, F_3 the spectral responses of filters, dichroic mirrors, etc., of the camera optical systems, then C and F can be adjusted to approximate the following relations:

$$C_1F_1 = K\bar{x}$$
$$C_2F_2 = K\bar{y}$$
$$C_3F_3 = K\bar{z}$$

which, if unchanged, will give $\bar{x}$, $\bar{y}$, and $\bar{z}$ as taking sensitivities. Having made this adjustment, it becomes possible, by matrixing, to obtain other sets of taking sensitivities, such as $\bar{r}$, $\bar{g}$, and $\bar{b}$, as desired.

C and F may be measured for any individual camera by subjecting it to narrow-wavelength bands of light whose individual relative energies are known with respect to any one of them. These approximately monochromatic sources can be obtained by passing collimated light from a known source through individual narrow-band filters and their associated Wratten filters. If the illuminant is a standard Illuminant A (tungsten at 2,854 degrees K color temperature) then the energy passing through the filter relative to that through other filters is

$$\text{Relative Energy }(\lambda_0) = \int_{400}^{700} A f_0 d\lambda \cong A \int_{400}^{700} f_0 d\lambda, \qquad (1)$$

where

λ_0 = peak wavelength of this filter.

A = relative energy of Illuminant A at wavelength λ.[2]

f_0 = transmission of narrow band filter and associated Wratten as a function of wavelength around λ_0.

$\int_{400}^{700} f_0 d\lambda$ = area under narrow band filter and Wratten transmission curve as measured with a planimeter.

These relative energies must be computed for each individual combination of narrow-band filter and Wratten when subjected to Illuminant A. The taking sensitivity at a given wavelength for any individual camera is then the camera tube output current divided by the relative energy of the narrow-band light source. A series of readings in the visible spectrum thereby yields the relative spectral sensitivity of that particular camera. The results are usually normalized on the basis of the peak reading.

Consider next a flying spot scanner wherein a cathode-ray tube is used as a light source. When the narrow-band filter is placed in the flying spot scanner slide holder the currents in the three channels are given by

$$i_1 = \int_{400}^{700} P C_1 F_1 f_0 d\lambda \cong P(\lambda_0) C_1(\lambda_0) F_1(\lambda_0) \int_{400}^{700} f_0 d\lambda \qquad (2)$$

$$i_2 = \int_{400}^{700} P C_2 F_2 f_0 d\lambda \cong P(\lambda_0) C_2(\lambda_0) F_2(\lambda_0) \int_{400}^{700} f_0 d\lambda \qquad (3)$$

$$i_3 = \int_{400}^{700} P C_3 F_3 f_0 d\lambda \cong P(\lambda_0) C_3(\lambda_0) F_3(\lambda_0) \int_{400}^{700} f_0 d\lambda, \qquad (4)$$

where

P = spectral distribution of cathode-ray tube illuminant.

C_n = spectral sensitivity of photocell in channel n.

F_n = spectral transmission of filters and dichroic mirrors associated with channel n.

f_0 = spectral transmission of narrow band filter and Wratten peaking at λ_0.

The spectral sensitivity S_n of channel n of the flying spot scanner at λ_0, then, is

$$S_n = P(\lambda_0) C_n(\lambda_0) F_n(\lambda_0) = \frac{i_n(\lambda_0)}{\int_{400}^{700} f_0 d\lambda}. \qquad (5)$$

Again a series of measurements is taken for filters peaking at different wavelengths throughout the visible spectrum and the relative sensitivity is calculated for each wavelength.

[2] A. C. Hardy, "Handbook of Colorimetry," The Technology Press, Mass. Inst. Tech., Cambridge, Mass., 1st ed., pp. 19–22; 1936.

The values of $\int_{400}^{700} f_0 d\lambda$ for the filter combinations used in this investigation are given in Table I. The preceding discussion is based on the assumption that the pass band of each narrow-band filter is much narrower than the pass band being measured if the integral approximations are to be valid. For example, suppose that a

TABLE I

Wavelength of Narrow-Band Optical Filter (millimicrons)	Wratten Filter	Normalized Filter Constants[1] $K(\lambda)$
400	2 pieces B glass	9.9405
422	2 pieces B glass	0.7444
449	No. 2B	0.7707
465	No. 2B	0.5073
484	No. 2B	0.6867
499	No. 4	0.6193
509	No. 4	1.000
525	No. 4	0.544
542	No. 9	0.8340
565	No. 15	0.8650
584	No. 16	0.5820
588	No. 16	0.5800
600	No. 21	0.4940
618	No. 23	0.4940
638	No. 23	0.8947
662	No. 29	0.6523
686	No. 29	0.8880
706	No. 29	0.5744
720	No. 29	0.9906

[1] Values of $K = \lambda \int_{400}^{700} d\lambda$ as explained under (1). These constants are valid only for the specific set of filters used in this work. They should be calculated for each set of filters separately.

photocell current of 28 microamperes is measured with the 600-millimicron filter combination in the flying spot scanner slide holder. Table I gives a value of $\int_{400}^{700} f_0 d\lambda$ equal to 0.494. The relative sensitivity at 600 millimicrons, then, is

$$\frac{28}{.494} = 56.7.$$

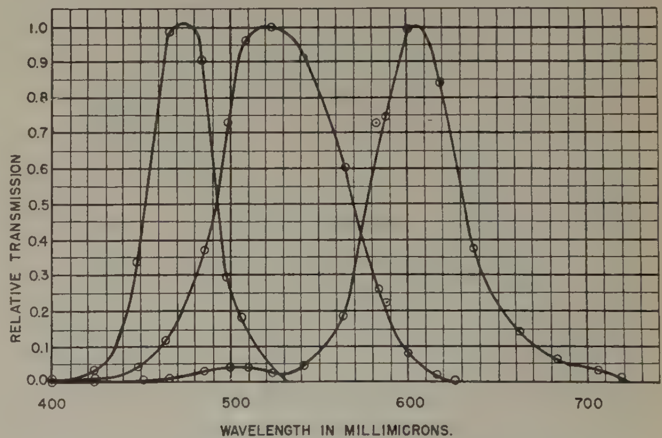

Fig. 3—Typical flying spot scanner taking sensitivity.

Fig. 3 gives the normalized plots of a series of such readings and calculations for each of the three channels of a typical color television flying spot scanner. These curves may now be either optically modified or electrically matrixed to give responses proportional to the desired taking sensitivities.

Measurement of Display Primaries

Spectral measurements of a display primary or other illuminant may be made with a spectrophotometer. The general layout of such a spectrophotometer is shown in Fig. 4. All of the elements involved except the calibrating illuminant were enclosed in a light-proof black box. The electrical circuit is shown in Fig. 5. In this work an experimental RCA phototube type C-7138 was used. A suitable equivalent is now available having the RETMA designation: 6217.

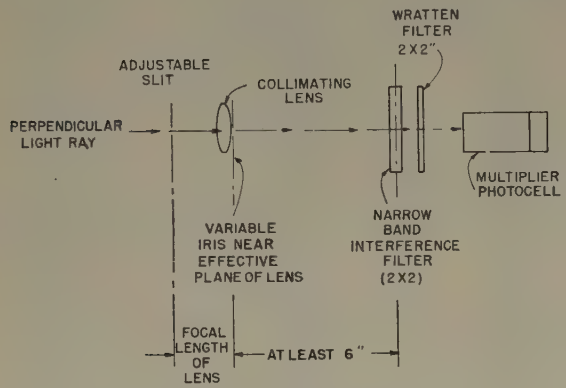

Fig. 4—Optical schematic.

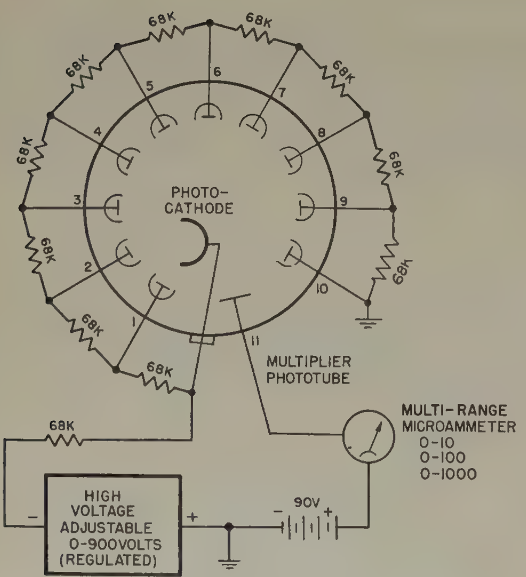

Fig. 5—Electrical schematic.

Before any measurements can be taken the device must be calibrated with a standard Illuminant A.[3] This is done by taking several sets of readings over different parts of the dynamic range of the phototube with Illuminant A and the filter combinations given in Table I. When each set of readings is normalized, corresponding readings should agree within one or two per cent.

After calibration, several sets of readings can be taken on the unknown illuminant. Again when the individual sets of readings are normalized corresponding readings should agree closely. For any given reading taken with a narrow band filter and Wratten of peak wavelength λ_0, the relative amplitude of the unknown illuminant is given by the following equation:

$$\text{Relative Amplitude at } \lambda_0 = \frac{I_I(\lambda_0)A(\lambda_0)}{I_A(\lambda_0)}. \tag{6}$$

$I_I(\lambda_0)$ = photocell current when subjected to unknown illuminant through filters peaking at λ_0.

$I_A(\lambda_0)$ = photocell current when subjected to Illuminant A through filters peaking at λ_0.

$A(\lambda_0)$ = relative amplitude of Illuminant A at wavelength λ_0.

The preceding formula is derived as follows. The photocell current when subjected to Illuminant A through filters peaking at λ_0 is

$$I_A(\lambda_0) = \int_{400}^{700} f_0 \text{ P.E. } A d\lambda \cong \text{P.E. }(\lambda_0)A(\lambda_0)\int_{400}^{700} f_0 d\lambda. \tag{7}$$

f_0 = spectral transmission of narrow band filter set peaking at λ_0.

P.E. = spectral sensitivity of photocell.

A = spectral distribution of Illuminant A.

If Illuminant A is replaced by the unknown illuminant, the photocell current becomes

$$I_I(\lambda_0) = \int_{400}^{700} f_0 \text{ P.E. } R_I d\lambda \cong \text{P.E. }(\lambda_0)I(\lambda_0)\int_{400}^{700} f_0 d\lambda. \tag{8}$$

R_I = spectral distribution of the unknown illuminant. The ratio of the last two equations can now be taken. Solving for $I_I(\lambda_0)$ gives (6).

As an example, suppose that a narrow band filter peaking at 600 millimicrons is placed in the spectrophotometer along with a No. 21 Wratten filter and the following readings are taken.

$$I_A(600) = 22.0 \ \mu a.$$

$$R_I(600) = 38.7 \ \mu a.$$

The relative energy of Illuminant A at 600 millimicrons is 1.29.[4] The value of I_I (600) is then given by

$$I_I(600) = \frac{38.7 \times 1.29}{22.0} = 2.24.$$

[3] The National Bureau of Standards in Washington will calibrate a light source, stating what value of input current is required for the source to be equal to Illuminant A.

[4] Hardy, *op. cit.*, p. 20.

The curve resulting from a series of such computations at different wavelengths (those corresponding to peak transmissions of the narrow-band filters) is the spectral characteristic of the unknown illuminant. Again it is the usual practice to normalize the resulting curve on the basis of unity as the maximum value.

Some typical measurements are shown in Fig. 6 which gives the spectral characteristics of a three-tube color television display using dichroic mirrors.

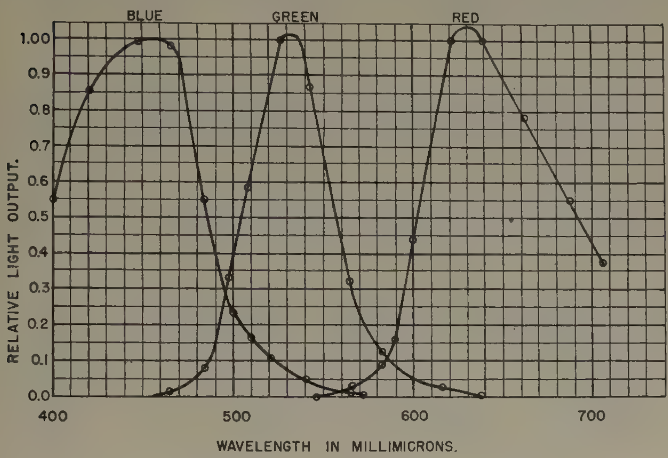

Fig. 6—Spectral curves of 3-tube dichroic display.

Computation of Tristimulus Values

The CIE tristimulus values can be computed from spectral curves by either the weighted-ordinate method or the selected-ordinate method.[5] It is recommended that the selected-ordinate method be used. Selected ordinates on the basis of equal-energy white are given in the November, 1944 issue of the *Journal of the Optical Society of America*.[6] Fig. 7 shows the positions on a CIE color chart of the dichroic display primaries of Fig. 6. The NTSC primaries and Illuminants *A* and *C* are plotted for comparison.

Measurement Precautions and Sources of Error

In all of the illuminant measurements, the direct current of the photocell should be measured with a large-scale microammeter capable of reading to 0.1 microampere such as Sensitive Research Model "University." No choppers or narrow-band amplifiers need then be used as is often common in such devices. Since the photocell is of the multiplier type, it is preferable to have the high-voltage supply regulated. Under these conditions there should be essentially no dc drift if the device to be measured is stable. Some difficulty may be encountered due to poor voltage regulation on the illuminants or the flying spot scanner being measured. A constant-voltage power transformer helps to minimize these drifting problems.

The high voltage should be shut off or the illuminant blanked when filters are being changed to avoid damage to the photocell or camera tube. At no time should the photocell peak current be permitted to exceed 750 microamperes. Some automatic protective circuits have been described.[7,8]

It must be remembered that all of the light being measured should pass through the narrow band filters perpendicularly. The peak wavelength may change appreciably if the filter is tilted only a few degrees, as shown in Fig. 2.

It is often true that the illuminant being measured does not have an even spatial distribution of light flux. For this reason, it is advisable to have a mechanically stable support for the spectrophotometer to avoid variations due to inadvertent scanning of the illuminant surface.

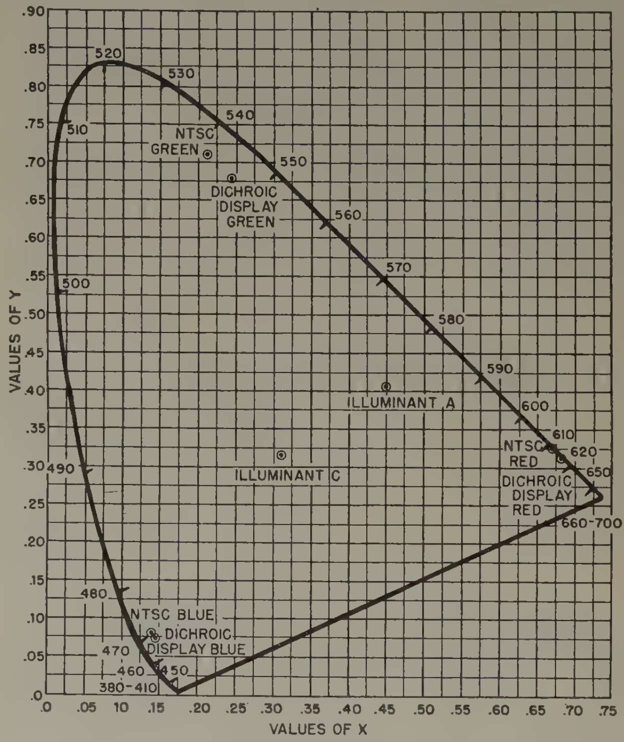

Fig. 7—CIE co-ordinates of dichroic display primaries.

Since all measurements are dc, it is advisable to darken the room in which the measurements are being taken when an illuminant is being measured. If the spectrophotometer is pointed towards a darkened corner, the current caused by the ambient light is generally unreadable. The box should be absolutely light-proof.

It was found that for the type 6217 red-sensitive photocell, the relation between anode current and light input is quite linear in the range from zero to a peak current of about 400 microamperes. The low duty cycle of some displays due to rapid decay phosphors must be

[5] Hardy, *op. cit.*, pp. 32–54.

[6] Committee on Colorimetry, "Quantitative data and methods for colorimetry," *Jour. Opt. Soc. of Amer.*, vol. 34, p. 649; November, 1944.

[7] M. H. Sweet, "An improved photomultiplier tube color densitometer," *Jour. Soc. Mot. Pic. & Telev. Eng.*, vol. 54; January, 1950.

[8] V. H. Seliger, "Optical feedback for multiplier phototubes," *Electronics*, p. 164; August, 1953.

allowed for, and therefore the average current correspondingly limited. The spectrophotometer current as read on a dc meter is an average value and some flying spot tubes may also saturate the photocell by reason of a large peak-to-average ratio, thus producing a very low average current. For example, in measuring a DuMont K1080P15 flying spot tube, the average photocell current must be kept under 50 microamperes to avoid exceeding the 400 microamp limit because of the rapid phosphor decay time. This is not a serious difficulty as long as the operator is aware of the decay characteristics of the phosphor or other illuminant he is measuring. Saturation in the phototube can be checked by substituting a resistive load and oscilloscope in the anode circuit of the phototube.

If reasonable care is taken in calibration and in taking readings, the error introduced in those steps should be no greater than two or three per cent. The greatest single source of error is probably the fact that the narrowband filters have transmission curves that broaden considerably below their half-power points. This would introduce no error if the illuminants to be measured had straight line characteristics over the filter pass band and if the filter transmission curves were geometrically symmetrical about their peak wavelengths. The symmetry is disturbed, however, by the Wratten filters.

Error may be introduced by this lack of symmetry when it is attempted to measure an illuminant with a spectral response having a steep slope. In one particular instance the error introduced by dissymmetry of the filter combinations was computed to be 7.5 per cent. This error is not considered excessive, since such an extreme case would not ordinarily be encountered in color television work.

Conclusions

This spectrophotometer and its associated filters comprise a method of obtaining quantitative spectral measurements with accuracy sufficient for most purposes. For sensitivity measurements, the filters provide one of the easiest available methods having reasonable accuracy. In comparison with other devices of similar accuracy, the filters and associated equipment are not unduly expensive and they are relatively easy to use.

Acknowledgement is due Mr. C. J. Hirsch and other members of the Research Division of the Hazeltine Corporation for their suggestions and encouragement in the development and use of this equipment.

Wide-Range Chromaticity Measurements with Photoelectric Colorimeter*

John B. Chatten†, associate, ire

Summary—**The addition of color to television has opened a new field of application for the science of color measurement. This paper discusses the need for objective colorimetric measurements in color television, and describes a photoelectric tristimulus colorimeter that has been developed for use in this field. This is an instrument for the objective measurement of chromaticity throughout the color gamut that is sufficiently accurate for general work in color television. The synthesis of the spectral characteristics of the instrument is discussed in detail.**

Introduction

At present, the most commonly used instrument for colorimetric measurements in color television work is the eye. There are two ways in which the eye is often used as a measuring device, and both have severe disadvantages as an engineering tool.

Quite often attempts are made to use the unaided eye for absolute judgment of chromaticity. Common examples of this are encountered in adjusting of white balance of displays, and also in judgment of saturation or vividness of colors in reproduction. It is true that good accuracy is not usually expected by those making such visual judgments, but still, it is not generally appreciated just how wrong such subjective judgments can be. Such things as adaptation, past history, and surround color affect these judgments. The literature on color is full of illustrations of color illusions, so they need not be discussed here. Visual judgment of chromaticity variations made by unaided eye, are, for most people, useful only as a crude type of estimation.

If the eye is used to compare two colors, it does much better. An observer can produce results in color-matching experiments that are repeatable to a good degree. This, of course, is basic in the science of color measurement, and numerous successful color-measuring instruments of the comparison type have been built. Unfortunately, however, there are significant variations between even so-called "normal" observers that confuse the issue. This, coupled with the fact that accurate color matching requires a somewhat complex judgment compared, say, to reading a meter, and is somewhat fatiguing, suggests that objective measurements would be desirable.

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All objective color measurement involves, in some manner, the creation of an artificial eye that has the color characteristics of an average normal observer. The characteristics used are those defined by International Commission on Illumination. This subject is fully covered in literature on colorimetry.[1] It is sufficient for the present discussion to state that the standard observer's color vision is defined by three spectral sensitivity characteristics, the well known $\bar{x}$, $\bar{y}$, and $\bar{z}$ curves.

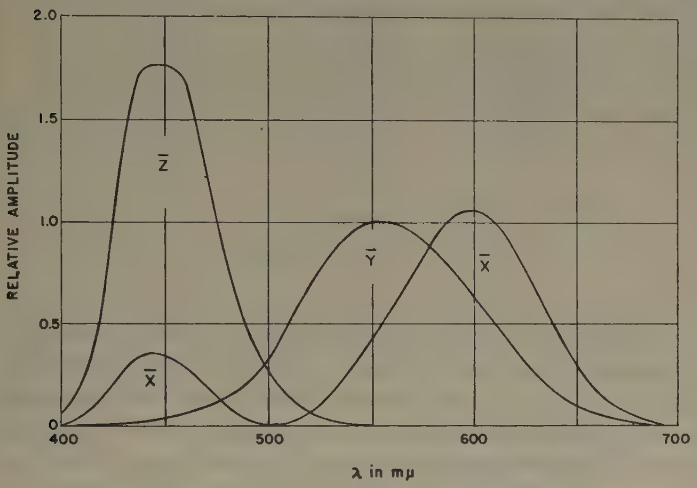

Fig. 1—Characteristics of CIE standard observer.

These are shown in Fig. 1. They represent the amounts of light from each of three primary sources that, when mixed, will produce light of a color that matches the pure spectrum color of wavelengths noted on the abscissa. The three amounts of primary light are the "tristimulus values" noted as X, Y, and Z. If the light being defined in this system is not of a pure spectrum color but rather consists of radiation of varying amounts throughout the visible spectrum, the tristimulus values are then:

$$X = \int E_\lambda \bar{x} d\lambda \qquad Y = \int E_\lambda \bar{y} d\lambda \qquad Z = \int E_\lambda \bar{z} d\lambda, \quad (1)$$

where E_λ is the function defining the radiant energy per unit wavelength versus wavelength of the unknown light. In order to define the chromaticity of a light, only the relative values of X, Y and Z are necessary. Chromaticity is usually expressed in terms of the trichromatic coefficients x and y which are defined as:

$$X = \frac{X}{X+Y+Z} \qquad Y = \frac{Y}{X+Y+Z}. \quad (2)$$

Theory of the Ideal Photoelectric Tristimulus Colorimeter

The ideal photoelectric tristimulus colorimeter is the simplest and most direct instrument for the measurement of chromaticity. If one shines the unknown light, characterized by E_λ, onto a photocell and, successively, places three filters in front of it, the three values of output will be:

$$I_1 = k \int E_\lambda T_{\lambda 1} S_\lambda d\lambda \qquad I_2 = k \int E_\lambda T_{\lambda 2} S_\lambda d\lambda$$
$$I_3 = k \int E_\lambda T_{\lambda 3} S_\lambda d\lambda. \quad (3)$$

where S_λ is the spectral sensitivity of the photocell and $T_{1\lambda}$, $T_{2\lambda}$ and $T_{3\lambda}$ are the spectral transmittance characteristics of the three filters. If $T_{1\lambda}$, $T_{2\lambda}$ and $T_{3\lambda}$ satisfy (4), then I_1, I_2, and I_3 will be the desired tristimulus values X, Y, and Z of the unknown light.

$$T_{\lambda 1} = \frac{\bar{x}}{s_\lambda} \qquad T_{\lambda 2} = \frac{\bar{y}}{s_\lambda} \qquad T_{\lambda 3} = \frac{\bar{z}}{s_\lambda}. \quad (4)$$

If one could find three filters and a photocell that accurately satisfy (4) he would have the ideal photoelectric tristimulus colorimeter. Unfortunately, such are not available. However, there are alternatives which will now be discussed.

The Three Filter Photoelectric Tristimulus Colorimeter

Referring to Fig. 1, the $\bar{x}$, $\bar{y}$ and $\bar{z}$ functions, it is seen that the $\bar{x}$ function is made up of two pass bands in the visible spectrum. It would be extremely difficult to secure a filter photocell combination that would accurately reproduce two pass bands such as these. This is the reason why nobody has made an "ideal photoelectric tristimulus colorimeter" as described above.

The "three filter colorimeter"[2] takes advantage of the similarity between $\bar{z}$ and the lower pass band of $\bar{x}$. Three filter-photocell combinations are used which have characteristics which approximate $\bar{y}$, $\bar{z}$ and the upper pass band of $\bar{x}$ (defined as $\bar{x}'$). When measuring an unknown light, a fraction of the output value from the $\bar{z}$ combination is added to that of the $\bar{x}'$ combination to compensate for the missing pass band.

This approach to the synthesis of the $\bar{x}$, $\bar{y}$ and $\bar{z}$ characteristics is, of course, an approximation because the $\bar{z}$ characteristic and the lower wavelength pass band of $\bar{x}$ are not identical in shape. An instrument using these characteristics, however, can be quite useful in restricted areas of the color gamut where it can be used as a comparison instrument. That is, it can be used to determine the difference between a standard, known color, such as white, and an unknown color having a chromaticity that is in the neighborhood of the standard. The results of the comparison can be expressed in the CIE system with an accuracy that is a function of the nearness of the two chromaticities.

Use of More Than Three Filters

The theoretical disadvantages of the three-filter colorimeter can be removed if one chooses to use a fourth filter-cell combination for the synthesis of the short wavelength pass band of the $\bar{x}$ characteristic.

[1] A. H. Hardy, "Handbook of Colorimetry," Technology Press, Cambridge, Mass.; 1936.

[2] R. S. Hunter, "Photoelectric Tristimulus Colorimetry With Three Filters," NBS Circular C 429; 1942.

However, a practical disadvantage remains in that it is difficult to make single filter-cell combinations that match characteristics such as $\bar{x}$, $\bar{y}$, or $\bar{z}$ with small tolerances at all wavelengths. This condition is necessary if accurate chromaticity measurements are to be made throughout the color gamut. However, successful colorimeters of this type have been built.[3] To do so requires photocells that are specially selected, on an individual basis, for certain spectral characteristics, and the making of special filters. Generally, several filters are used in cascade for the synthesis of each characteristic.

It is possible to obtain the desired $\bar{x}$, $\bar{y}$, and $\bar{z}$ characteristics, with good accuracy, without resorting to special melts of filter glass if one is willing to use more than four filter-cell combinations. The general approach is to choose three filter-cell combinations that have characteristics close to the desired $\bar{x}$, $\bar{y}$, and $\bar{z}$ curves, and then arrange supplementary combinations that synthesize the error characteristics and to use measurements made with these to correct the original. This process can be continued until the desired degree of accuracy is obtained or until the limit of calibrating accuracy is reached. We found several combinations of these type that yielded good over-all results. The simplest of these used five filters, and is the combination used in the colorimeter described in this paper.

Optical and Electrical Design

It was decided to use only one photocell in the construction of the colorimeter. The five filters are placed, sequentially, in the light path to produce the five different filter-cell combinations. This choice, in preference to the use of a separate photocell for each filter-cell combination, not only reduced the bulk of the instrument but also eliminated the need for recalibrating the instrument before each use. This recalibration would be necessary to compensate for drift of photocell sensitivity if there were several cells involved. If the photocell changes sensitivity in a single cell instrument, it is unimportant because all readings on a given color would be changed in proportion, and it is only the relative values of X, Y, and Z that are of significance if chromaticity is being measured.

Fig. 2 is a schematic picture of the optical system of the colorimeter. The photocell is a barrier-type cell, Weston Type 3RR. This type was chosen for two reasons. It is quite stable, so that there is good assurance that it will not drift during the time that the five filters are being placed in the light path, and its spectral sensitivity characteristic is such that it can be used, fairly easily, as a component in the filter-cell combinations stimulating $\bar{x}$, $\bar{y}$, and $\bar{z}$.

The lens system is arranged to facilitate the setting up of various types of measurements likely to be encountered in color television work. The objective lens focuses the light emitting (or reflecting) surface to be measured in a plane 4 inches behind it. The mechanical arrangement is such that it is convenient to place a ground-glass surface in the image plane and by observing the image, aim the colorimeter as one would a reflex-type camera. An adjustable iris is provided in the image plane the purpose of which is to mask down the image so that light is accepted only from that portion

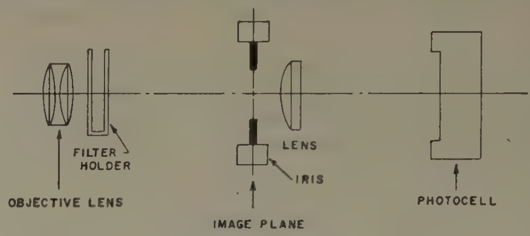

Fig. 2—Optical system.

of the surface having the chromaticity one wishes to measure. The ground glass is removed before measurements are made. The second lens focuses the exit pupil of the objective lens on the active surface of the photocell. This arrangement insures that the same area of the photocell will be used, and will be illuminated in the same relative way, regardless of the nature of the intensity variations on the surface being measured or of the setting of the iris. This is desirable because some photocells show significant variations of characteristics over the active surface. The filter holder is located immediately behind the objective lens, where the light beam is considerably out of focus.

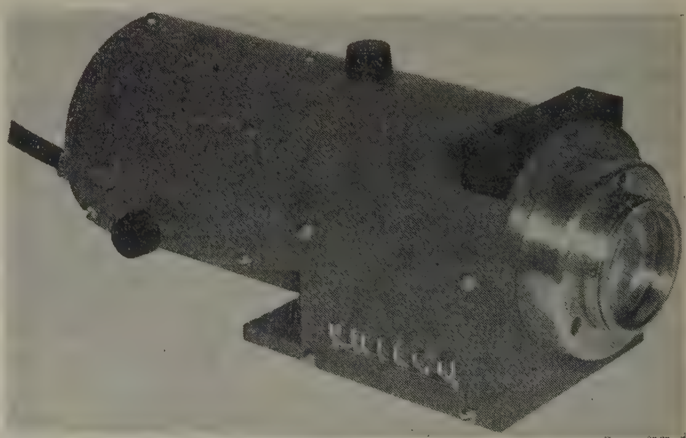

Fig. 3—Complete colorimeter.

The instrument, as designed, can measure chromaticity of surfaces having brightnesses as low as two foot lamberts (on white) with good accuracy. (This same accuracy holds for lower brightness values for saturated colors because the accuracy is more a function of the light energy emitted by the surface than of brightness.) In order to work at these brightness levels, however, a very sensitive current detector is necessary.

[3] B. T. Barnes, "Four filter photoelectric colorimeter," *Jour. Opt. Soc. Amer.*, p. 448; 1939.

The photocell currents in this brightness range are of the order of 0.02 μamps. A Leeds and Northrup type 2430D galvanometer with a sensitivity of 0.0004 μamps/mm was found quite satisfactory for this purpose. These rather low values of output current are due, to a large extent, to the fact that some of the filters used are quite dense. The densest, an intereference filter, would transmit only 2 per cent of white light.

Fig. 3 is a photograph of the complete instrument. The slot immediately behind the objective lens is the "filter holder" of Fig. 2. The rear section of the instrument can be removed to expose the image plane and iris. This is useful when setting up a measurement as is described above.

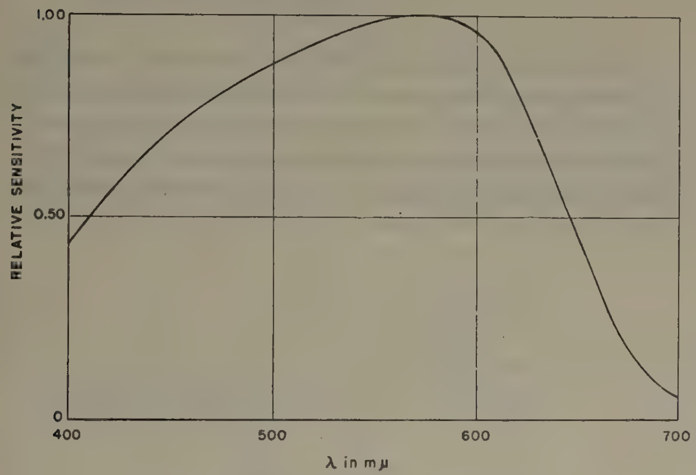

Fig. 4—Spectral sensitivity of photocell.

Synthesis of Spectral Characteristics

The spectral sensitivity, S_λ, of the photocell used is shown in Fig. 4. This cell is seen to have good sensitivity over the visible spectrum, and the characteristic shows no abrupt changes in this range. These are both desirable properties.

The ideal filter characteristic $T_{\lambda 1}$, $T_{\lambda 2}$, and $T_{\lambda 3}$ in accordance with (4), and the real component filter characteristic are shown in Fig. 5. The solid lines represent the ideal filter-transmission characteristics, and the broken lines represent the transmission characteristics of the real component filters used to synthesize the ideal. The object here is to find filters having characteristics which can be summed point by point and result in the ideal characteristic. In each case we tried to find one filter, called the "primary filter" which, by itself, came close to synthesizing the ideal, and then to find supplementary filters to compensate for the discrepancies between the primary and the ideal.

When looking for filters, the absolute values of transmission are unimportant. They can be altered by the use of neutral density filters, or, when being used, the output readings can be multiplied by a constant. Thus the component-filter characteristics in (Fig. 5) are plotted with ordinates equal to actual transmission values multiplied by a constant which make the curves fit. The actual spectral transmission curves were determined with a recording spectrophotometer of the Hardy type.

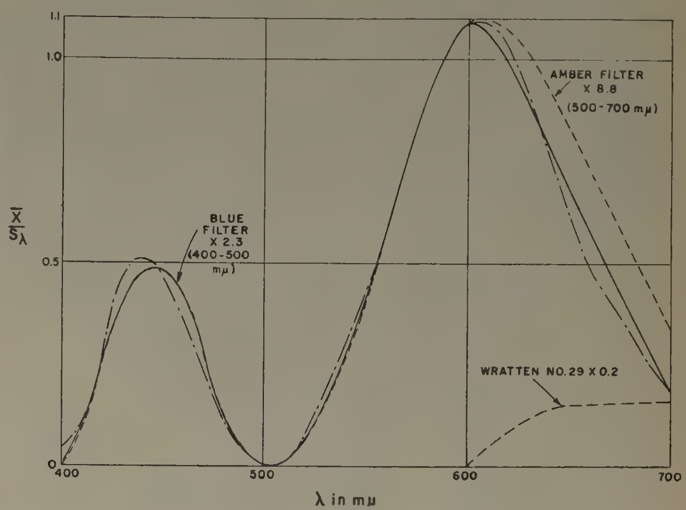

Fig. 5(a)—Synthesis of $T_{\lambda 1}$.

Fig. 5(c) shows the synthesis of the $\bar{z}$ filter. The primary filter is a glass filter of the type used in a three-filter colorimeter and is identified as the "blue-filter." It is seen that its characteristic fits the ideal fairly well except in the region 470 to 540 mμ. The discrepancy here can be synthesized by the characteristic of an interference filter. Thus, if readings are taken using the blue filter and the interference filter, in turn, and the readings are multiplied by 12.0 and 1.7 respectively, and then are summed, the result will be very close to that which would be obtained if a reading were made through the ideal filter.

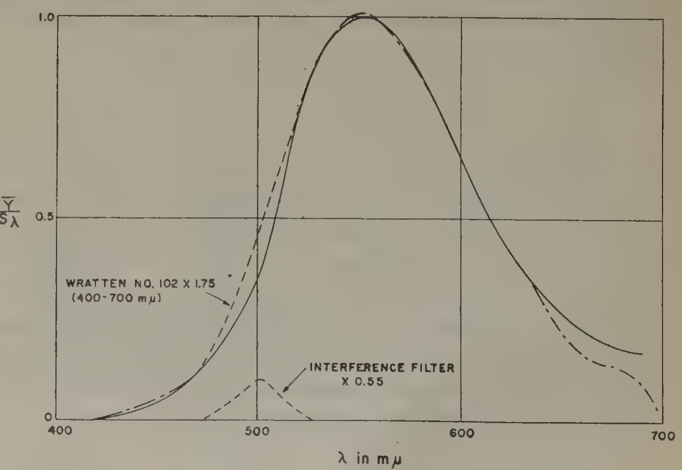

Fig. 5(b)—Synthesis of $T_{\lambda 2}$.

The primary filter in the synthesis of the $T_{\lambda 2}$ characteristic is a wratten gelatin filter type 102. It fits the ideal satisfactorily except in the region about 500 mμ. Here, again, the discrepancy can be synthesized by the same interference filter used for $T_{\lambda 3}$. Note that the

filter must be used in the negative sense to effect the compensation. This causes no trouble since we combine the readings on paper.

The synthesis of the $T_{\lambda 1}$ characteristic used two primary filters. The lower pass band is formed by the same "blue" filter used for $T_{\lambda 3}$ and the upper pass band uses another glass filter, "amber," as the primary filter. A wratten gelatin filter type 29 is used as a supplementary filter to compensate for the discrepancy existing in the range between 600 and 700 mμ and is used in the negative sense.

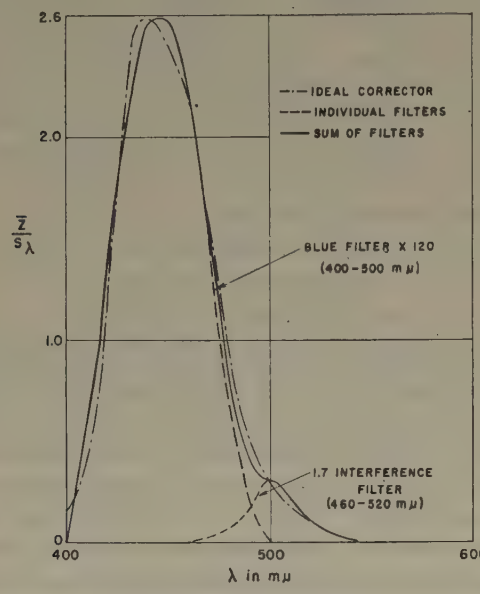

Fig. 5(c)—Synthesis of $T_{\lambda 3}$.

When component filters in Fig. 5 are combined and multiplied by spectral sensitivity of the photocell, S_λ, in Fig. 4, there results the spectral characteristics of the colorimeter. These are in Fig. 6, along with $\bar{x}$, $\bar{y}$, and $\bar{z}$ characteristics they should match.

Colorimetric Accuracy

The accuracy of the colorimeter was checked by using it to measure the chromaticity of some known colors spaced around the chromaticity diagram. These colors were produced by shining a calibrated Illuminant A source onto a flat white surface (M_nO_2) and placing gelatin filters of known transmission characteristics in the light path. The results of these measurements are shown in Fig. 7. The spectrum locus and the NTSC triangle of primaries are shown for reference.

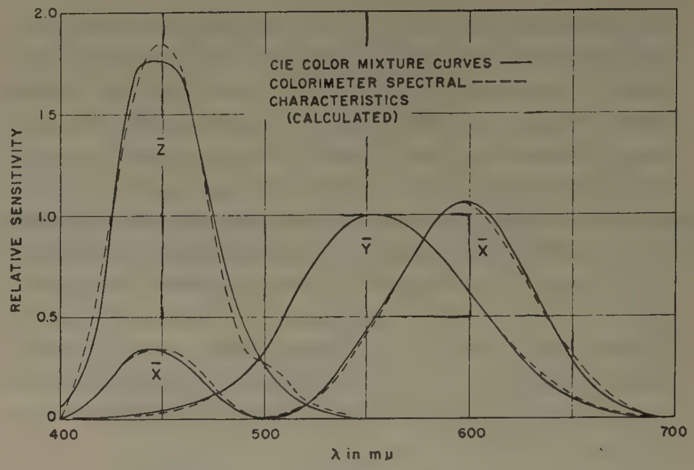

Fig. 6—Final spectral characteristics of colorimeter.

The accuracy shown in Fig. 7 is more than adequate for the bulk of color television work. The errors shown could be detected visually only under ideal viewing condition when two colors are compared in a split field. Their magnitude is of the order of two minimum perceptible color differences.

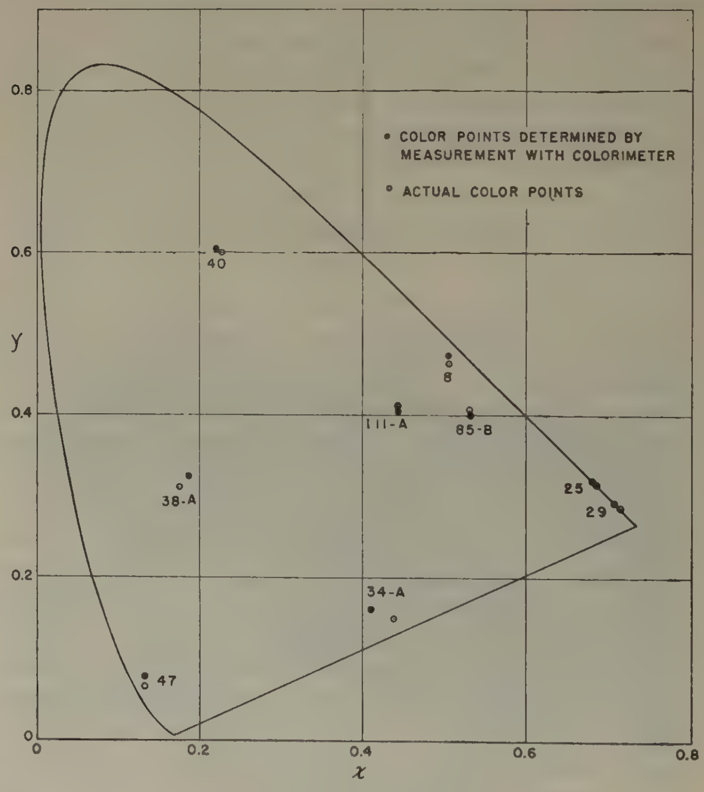

Fig. 7—Chromaticity measurements made with colorimeter.

Image Orthicons for Color Cameras*

R. G. NEUHAUSER†, A. A. ROTOW†, SENIOR MEMBER, IRE, AND F. S. VEITH†, SENIOR MEMBER, IRE

Summary—**The image orthicon is the only pickup tube commercially available that possesses the high sensitivity required for color cameras. However, the demands of a color picture are such that the standard image orthicon requires changes in design, processing, and testing in order to fulfill this function. These requirements have led to the development of a special image orthicon for color, the RCA-1854. The operating conditions for the new tube are substantially different from those used in monochrome practice. These new conditions change the performance characteristics of the tube and the character of the reproduced picture.**

Introduction

PENDING DEVELOPMENT of a practical, commercial model single camera tube suitable for color work, three image orthicons are being used at present to produce the information necessary for the formation of a color-television image.[1-3] A typical three-channel color-camera arrangement is shown in Fig. 1.

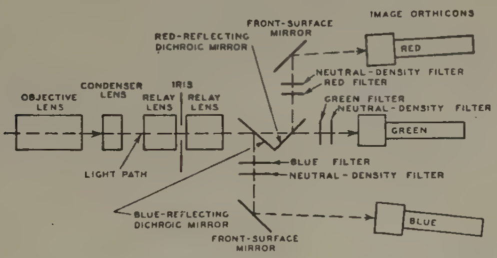

Fig. 1—Block diagram of the optical system and general physical relation of components in a color camera utilizing three RCA-1854 image orthicons.

The dichroic mirrors and color filters associated with each channel produce the "taking" characteristic shown in Fig. 2, so that each image orthicon is required to translate only a portion of the visible spectrum into video information. Each tube must operate on a substantially constant-gamma curve in order to prevent distortion of the color information in the video signal obtained from the three color channels. This requirement necessitates operating each image orthicon entirely below the knee of its transfer characteristic.[4]

Signal-to-Noise Ratio and Contrast Range

In order to provide a signal-to-noise ratio and a contrast range adequate for both color and monochrome reproduction of the color signal it is necessary to raise the upper limit of the constant-gamma region to give the peak highlight signal the highest possible value without extending operation into the knee of the transfer characteristic.[5]

These objectives are attained in the RCA-1854 image orthicon by increasing the capacitance of the storage element formed by the glass target and collector mesh.

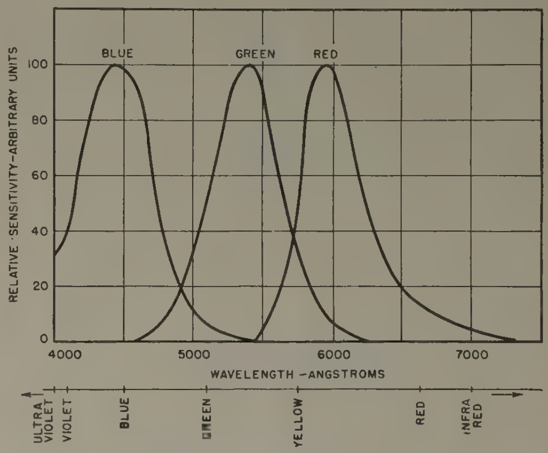

Fig. 2—Spectral response characteristics of the individual color channels of the three-tube image orthicon color camera.

This capacitance is determined by the spacing between target and mesh. Reducing the target-to-mesh spacing from the value of 0.0025 inch used in the 5820 image orthicon to 0.001 inch in the RCA-1854 increases the highlight signal output to the extent shown in Fig. 3.

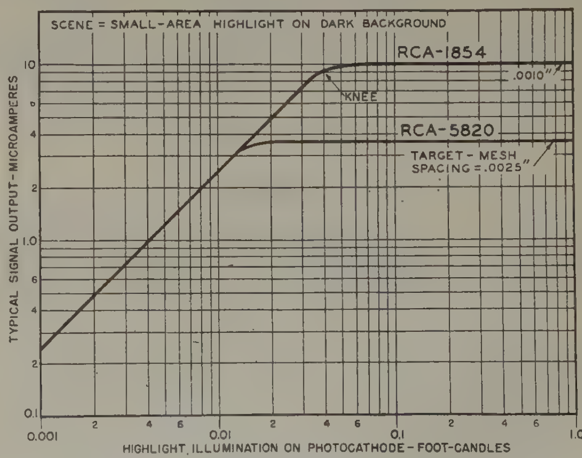

Fig. 3—Improvement in transfer characteristic obtained by the use of 0.001-inch target-to-mesh spacing in the RCA-1854 image orthicon.

* Decimal classification: R583.6. Original manuscript received by the Institute, October 26, 1953.

† Radio Corp. of America, Lancaster, Pa.

[1] J. R. DeBaun, R. A. Montfort and A. A. Walsh, "The NBC New York color television field test studio," *RCA Rev.*, vol. XIII, pp. 107–124; March, 1952.

[2] J. D. Spradlin, "The RCA color television camera chain," *RCA Rev.*, vol. XIII, pp. 11–26; March, 1952.

[3] L. T. Sachtleben, D. J. Parker, G. L. Allee and E. Kornstein, "Image orthicon color television camera optical system," *RCA Rev.*, vol. XIII, pp. 27–33; March, 1952.

[4] R. B. Janes and A. A. Rotow, "Light-transfer characteristics of image orthicons," *RCA Rev.*, vol. XI, pp. 364–376; September, 1950.

[5] Operation along a nonlinear portion of a transfer characteristic is not objectionable in general. In the image orthicon, however, any departure from a unity gamma characteristic represents charge lost through electron redistribution. This random redistribution over the target area interferes with accurate color reproduction.

Although contrast in a color picture is primarily achieved by hue rather than by brightness information, good contrast is of importance particularly for reception of the color picture on monochrome receivers. The advantage provided by the close target-to-mesh spacing gives the new image orthicon wide contrast range and a signal-to-noise ratio of 60 to 1 when operated with the highlights just below the knee of the transfer characteristic. The loss of signal-to-noise ratio due to the insertion of gamma correction, which is needed in the color system, can easily be tolerated.[6]

The chosen close target-to-mesh spacing of the RCA-1854 reduces the influence of the inter-element capacitance of the target and eliminates effectively the white-edge effects typical of wider-spaced tubes. Also, problems of "ghost," "white halo," and "black border," sometimes encountered in monochrome practice, do not present themselves in color work with the use of the close-spaced tube since in the operating range under the knee of the transfer characteristic there is little or no redistribution of secondary electrons over adjacent picture areas.

Reduction of the target-to-mesh spacing below the 0.001 inch value adopted for the RCA-1854 image orthicon would introduce several undesirable effects. Extremely close-spaced tubes suffer from excessive "lag" or smearing of moving objects, and from variations in signal output caused by random pulling together of the target and the collector mesh over the scanned area of the target. The "lag" in color work is normally slightly higher than in monochrome practice, due primarily to the fact that in the color camera the image orthicon is operated with "full" rather than with "partial-storage." The condition known as "partial storage" is caused by electron redistribution over the target when an image orthicon is operated with the high lights on or above the knee of the transfer characteristic. This condition is inherent in present monochrome television systems due to the practice of utilizing the knee of the image orthicon characteristic to compensate for the greater-than-unity gamma of black-and-white receiver kinescopes.

Illumination

The neutral-density filters shown in Fig. 1 are used to compensate for the different sensitivities of individual image orthicons by balancing the illumination levels so that all three tubes operate over identical regions of their transfer characteristics. These filters are required for two reasons. First, it is virtually impossible to control the sensitivities of image orthicons during manufacture with sufficient precision to meet the extremely close tolerances required in the color camera. Second, the normal differences in the light-transmission characteristics of the red, green, and blue color filters result in unequal light inputs to the three tubes unless suitable compensation is provided.

Both of these variable factors can be adjusted by the insertion of the proper amount of neutral-density filtering in one or more channels. The necessary adjustments to determine the proper operating point are made with the aid of a neutral step pattern. The first step in the procedure is to determine the upper limit of the linear transfer characteristic for the channel of lowest sensitivity. This determination is made with only the dichroics and color filters in place by opening the lens to the point at which the output of the reference channel on the highest step of the pattern fails to rise as steeply as the output on the lower steps. This determines the start of the knee of the transfer characteristic. The desired operating point is then established by closing the lens to an aperture one-half stop smaller to insure that operation will be confined substantially to a constant-gamma portion of the tube's characteristic. Sufficient neutral-density filtering is then inserted in each of the other two channels to bring all three tubes to the same operating point at this lens aperture. (With tungsten illumination the green channel is normally the channel of highest sensitivity and requires the densest neutral filters to match it to the other channels. It is customary, therefore, to use the image orthicon with the lowest sensitivity in the green channel of the camera.) Because there are substantial differences in the spectral distribution of light from various sources, each type of illuminant requires a different set of color filters and a corresponding change in the neutral-density filters to maintain identical operating points in the three channels.

Registration

If the optical system is correctly designed and adjusted, it is relatively easy to produce optical images of equal magnification, properly focused and centered, on the photocathodes of the three image orthicons. Given these conditions, and assuming perfect demagnification and transfer of the resulting electron image from the photocathode to the target of each image orthicon, registration of the three images then becomes merely a matter of scanning registration. In practice, however, there may be some distortion of the electron image in one or more of the image orthicons which will require correction by adjustment of tube-operating potentials or scanning-circuit characteristics.

For example, improper or dissimilar operating voltages on the tubes may tend to cause "S-distortion," "pincushion," or "barrel" effects. Structurally, lack of axial

[6] In the compatible color-television system the luminance component of the color signal is derived in the "colorplexer" unit by mixing the signals from the three color channels in the following proportions: green, 1; red, 0.5; blue, 0.16. The luminance value of a maximum-white signal will, therefore, be the arithmetical sum of the three single-color maximum values, or 1.66. The rms-noise currents of the three signals, however, mix *in quadrature* rather than by direct addition, and the resulting noise will be expressed as $\sqrt{1^2+0.5^2+0.16^2}$, or 1.13. The signal-to-noise ratio of the multiplexed color signal will thus be

$$\frac{S_c}{N_c} = \frac{S_1}{N_1} \times \frac{1.66}{1.13} = \frac{60}{1} \times \frac{1.54}{1} = \frac{88}{1}.$$

This calculation does not take into consideration the loss in signal-to-noise ratio introduced in the gamma correction circuits.

symmetry in the tube electrodes will produce distortions that do not have the axial symmetry of these forms. Effects noted in the development of the image orthicon for color indicate that particular attention must be paid to the spacing between the grid-No. 6 electrode[7] and the photocathode. Small variations in this spacing will produce "S-distortions" and changes in image demagnification. The spacing between grid-No. 5 and the wall coating, and between grid-No. 5 and the target assembly also affect the nature of the scanning raster on the target.

In order to prevent the introduction of forms of distortion that are axially nonsymmetrical, extremely close tolerances are applied in the manufacture of the RCA-1854 image orthicon to insure circularity of all cylindrical electrodes. These precautions, and the provision in the equipment of individual controls for the amplitude, linearity, and centering of each deflection field, as well as controls to compensate for deflection-coil skew, enable the camera operator to produce excellent registration of the three pictures.

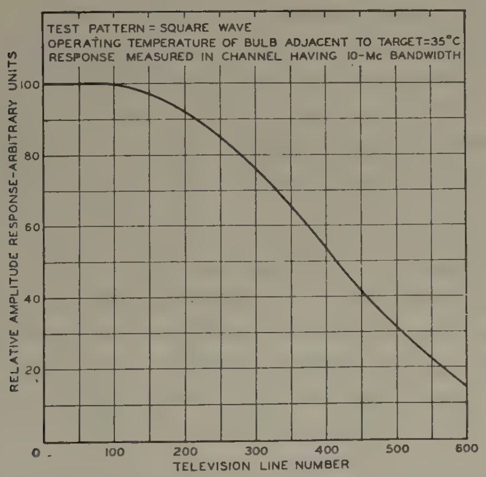

Fig. 4—Amplitude response of the 1854 image orthicon at the recommended bulb temperature of 35 degrees Centigrade.

Resolution

A high degree of resolution in the individual camera tubes is an important requirement for color. Due to the fact that three images must be superimposed exactly, event slight misregistrations will exaggerate any deficiencies in resolution. If the individual channels of a three-color camera have poor resolving capabilities, sharp lines or small details will be spread out wider in the final picture than if the scene were viewed on a single-channel color or monochrome system with comparable resolving capabilities.

In the course of investigating the operation of image orthicons in color cameras, it was found that the resolving capabilities of the tubes are materially affected by the operating temperature. The amplitude response[8] of the RCA-1854 at normal operating temperatures is shown in Fig. 4, while Fig. 5 shows the deterioration in resolution that results when the temperature of the tube is increased. At temperatures above 45 degrees Centigrade the resolution tends to drop due to a decrease in the resistivity of the target glass. Another

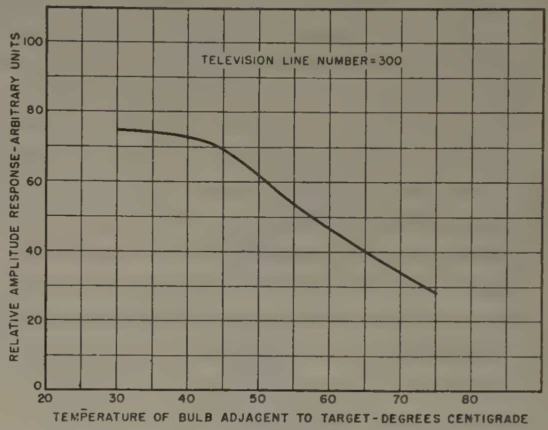

Fig. 5—Effect of bulb temperature on the amplitude response of the 1854 for 300-line information.

temperature effect is that uneven heating of the tube causes a migration of cesium from the photocathode to the cooler parts. If the target is the coolest element of the tube the excess cesium deposited on the target surface by this migration will tend to cause permanent loss of resolution by decreasing the surface resistivity and allowing lateral leakage of the image charges. Little can be done in the design or manufacture of the image orthicon to prevent this effect, because the cesium must be present for activation of the photo-surface. Therefore the cooling system must be designed to keep the temperature of the bulb adjacent to the target below the maximum permissible value of 45 degrees Centigrade, while maintaining the rest of the bulb at the same or lower temperature to minimize the migration of cesium to the target.

Spectral Characteristics

The spectral characteristics of the standard image orthicon are such that no major changes are needed to adapt it for use in color systems. The spectral response of the image orthicon photo-surface is shown in Fig. 6. It can be seen that the area of highest sensitivity is in the blue region of the spectrum. When used in a studio with incandescent light the blue and red channels (of the camera) have nearly equal sensitivities, due to the fact that the red light emitted by a tungsten illuminant has very high intensity with respect to the blue component, and also to the fact that the blue filters normally used have rather low transmission. (It has been found necessary to use tungsten light exclusively in studio work for color. Fluorescent light should not be used because the

[7] R. B. Janes, R. E. Johnson and R. S. Moore, "Development and performance of television camera tubes," *RCA Rev.*, vol. X, pp. 191–223; June, 1949.

[8] O. H. Schade, "Electro-optical characteristics of television systems, part III," *RCA Rev.*, vol. IX, pp. 490–530; September, 1948.

spectral lines of the mercury-vapor exciter create discontinuities in the output of the phosphor illuminant which produce severe color distortions.)

Shading and Signal Uniformity

The production of a satisfactory simultaneous color picture from the outputs of three image orthicons predicates stringent requirements as to uniformity of output. First, of course, the sensitivities of the three tubes at all points on the raster must not differ by more than a very small percentage. Second, the black-level or dark signals of the tubes must match even more closely than their responses under illumination. This last requirement is particularly vital to insure that dark portions of color areas will have the correct hues, and that dark seportions of neutral areas *will not* have hue. It has been found that if the video signal produced by a dark area which has 10 per cent of the reflectance of the highlights contains unwanted variations with an amplitude of only 2 per cent of peak-signal value, the color of the dark area will be distorted by as much as 20 per cent in reproduction. For example, if the normally equal red, green, and blue components of a dark neutral area are reproduced with values equal to 0.1, 0.08, and 0.1 of peak signal, respectively, due to the presence of a spurious variation in the green signal, the dark area will appear purple rather than neutral in the reproduction.

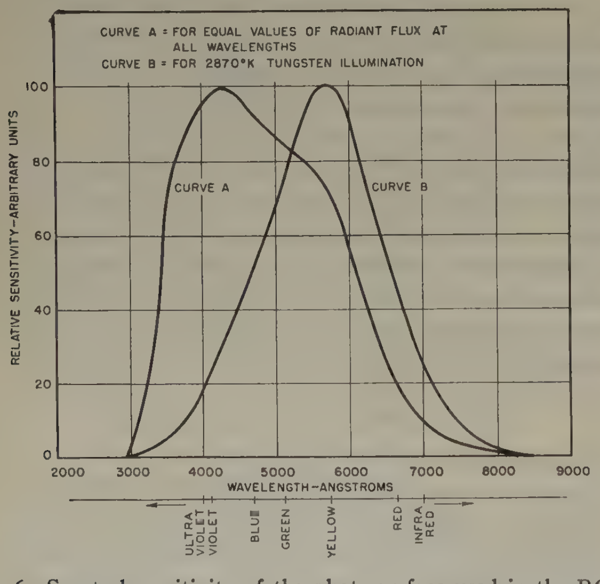

Fig. 6—Spectral sensitivity of the photo-surface used in the RCA-1854 image orthicon. Curve A—over-all response. Curve B—response to 2,870-degree-Centigrade tungsten illumination.

The requirement of equal sensitivity has been met by the use of the manufacturing and operating techniques described above. Next to be considered is the elimination or reduction of variations (called "shading") in the black-level signal. In total darkness, the full scanning beam of an image orthicon is returned to the first dynode of the built-in electron multiplier. Due to the fact that the return beam normally scans a small area of the first dynode, slight differences in secondary emission over this area are equivalent to variations in the current gain of the multiplier and thus superimpose a spurious "shading signal" on the normal black-level output of the tube.

To reduce such variations in dark current to the smallest possible values, particular care is used in the manufacture of the RCA-1854 image orthicon to produce exceptionally uniform secondary-emitting surfaces on the first and second dynodes. In addition, the high value of beam current at which the 1854 operates (approximately 3 to 4 times the beam current of the RCA-5820 image orthicon) accentuates the normal raster burn on the surface of the first dynode. To minimize the effect of this burn, the first dynode of each RCA-1854 image orthicon is aged during processing to produce a stable secondary-emission surface which is "burned" uniformly over the entire dynode area. As a further refinement, suggested by the fact that the mechanism for collecting these secondary emissions may also contribute a spurious component to the dark signal, the gun and multiplier structures have been improved to assure axial symmetry of the electrical fields controlling the collection of secondary electrons from the first dynode.

Electrical correction of a portion of the spurious signal can be achieved by the addition of sawtooth and parabolic wave forms to the video signal of each channel to cancel out the tilt produced by the shading signal. However, the addition of such shading-correction signals in one channel tends to cause a slight mismatch between its highlight and mid-range signals and those of the other channels. Some image orthicons may introduce spurious signals which have shapes that cannot be balanced out by this method, and which will interfere with proper image reproduction. These spurious signals exhibit a characteristic called "cross shading," and are generated, for example, when the black-level signal of the tube tilts in one direction at the top of the raster and in the opposite direction at the bottom. As a precaution against such effects each image orthicon is tested in a camera equipped with the same shading controls as those in a standard color camera, and only tubes having shading components that can be balanced out by electrical means are passed.

In addition to the corrective and selective measures described above, proper operation of the image orthicon can reduce some of the troubles normally associated with shading components. The use of the minimum value of beam current required to discharge the highest highlights is of considerable help, because excess beam current accentuates the spurious shading signal and adds nothing but noise to the useful output.

Spurious components in the signal output of an image orthicon other than those caused by shading signals are referred to as "landing variations," since they represent variations in the signal developed when the scanning beam actually lands on the target. There are several possible causes of variation in landing-signal

uniformity, of which the most obvious is uneven sensitivity over the exposed surface of the photocathode. Other predominant factors are the secondary-emission ratios of the glass target and the first dynode. Second-order effects are contributed by nonuniform spacing between target and collector mesh over the scanned area of the target, and by radial-velocity components which may be introduced into the scanning beam by deflection and alignment fields. Such radial-velocity components subtract from the velocity of the scanning beam normal to the target, with the result that the beam does not drive the target to the same potential at all points. It has been found that image orthicons which require high alignment currents tend to have poor landing characteristics and slight (but objectionable) geometric distortions. For these reasons, gun-alignment tolerances have been tightened considerably, with a resulting improvement in landing characteristics and a reduction in geometric distortion. Special tests have been formulated which allow precise measurement of the cumulative effects of all the foregoing factors on the sensitivity of the image orthicon at every point of the raster. These tests show up deficiencies that would not be apparent in an ordinary oscilloscopic presentation of the video output signals. It is, therefore, possible to set rigid specifications and maintain close control of product quality to insure signal uniformity.

In addition to these special processing techniques, a method of operation has evolved which reduces the second-order effects caused by nonuniform target-to-mesh spacing and the presence of radial-velocity components in the scanning beam. Both of these contributing factors can be minimized by operating the collector mesh at higher voltages than are normally used in image-orthicon practice. In this method of operation the tubes are first adjusted to the desired operating point in the manner described earlier in this article with a potential of 2 volts above the target-cutoff value applied to the collector mesh. Then, with no change in lens opening, the target voltage is increased to approximately 4.5 volts. This shifts the transfer characteristic of the tube to the extent indicated in Fig. 7, which produces a slight increase in signal output, particularly in the highlight region. The lens is then stopped down slightly to restore the signal to the amplitude obtained previously with a maximum charge buildup of 2 volts on the target.

This method of operation allows almost complete collection of the secondary electrons from the target, and achieves a substantially linear transfer characteristic with the desired unity gamma. As a result, there is little or no redistribution of the secondaries over the target, and the charge neutralized in each frame by the scanning beam will equal the charge deposited on the target by the photo-electrons. Therefore, variations in target-to-mesh spacing and capacitance will not affect the signal output. Furthermore, the relatively large difference between the fixed potential on the collector mesh and the average voltage to which the target is driven by the scanning beam reduces to negligible levels the effects of variations in target potential caused by radial-velocity components in the scanning beam.

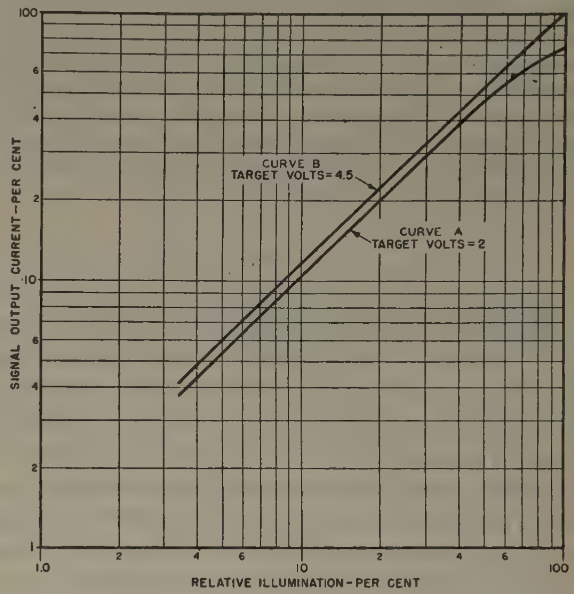

Fig. 7—Dynamic transfer characteristics of the RCA-1854 image orthicon at typical studio light levels used for color transmission. Curve A—with collector mesh at 2 volts above target-cutoff value. Curve B—with collector mesh at 4.5 volts above target-cutoff value.

The RCA-1854 developed for color television is inherently the best image orthicon available with respect to signal uniformity, resolution, and freedom from spurious signals.

Reproduction of Colors in Outdoor Scenes*

D. L. MacADAM†

Summary—Available spectrophotometric and colorimetric data on the colors of skin, hair, grass, foliage, sky, and earth are summarized. Typical reproductions of such colors in Kodachrome and some professional 35 mm motion-picture release prints have been measured and are shown. The results of some judgments for color quality are compared on the basis of these measurements. The results are also compared with previous measurements made on color reproductions in reflection prints. In the case of the reproduction of human skin, the preference seems to be for exact color reproduction in transparencies, although the fact, previously reported, that this is not so in the case of reflection prints, is confirmed by new data. The tolerance for color reproduction is much greater for transparencies than for reflection prints.

Introduction

OF THE COLORS that occur naturally in outdoor scenes, the most frequent can be grouped into a very few classes. Of the scenes that are photographed, perhaps the majority include persons, and therefore the reproduction of human skin is very important. There is a wide variety of natural skin colors, and consequently of acceptable reproductions of such colors. However, the range of acceptable reproductions is distinctly limited, and determination of that range is essential if high-quality color reproduction is to be accomplished.

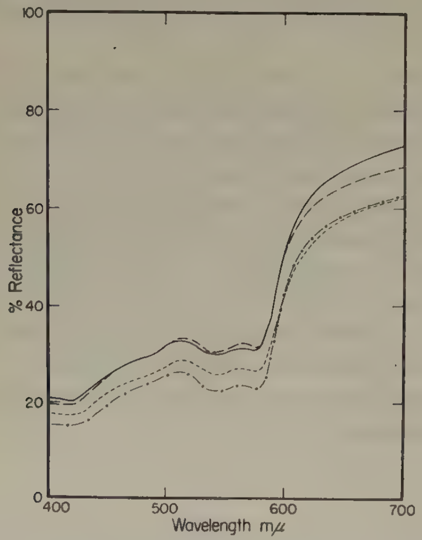

Fig. 1—Spectral reflectance curves of red cheek (top, solid curve), pale cheek (long dashes), forehead (short dashes), and side of neck (dot-dash) of girl. (From Edwards and Duntley.[1])

Perhaps the next most important class of colors photographed outdoors is that which includes foliage and grass. These colors also exhibit a great variety in nature, and a corresponding variety is to be expected and desired in color reproductions. The blue of the clear sky is prominent in many color photographs. Although the color of the blue sky is subject to great variations, not all of the variations observed in color reproductions are to be attributed to natural causes. A comparison of the range of natural sky colors with the range of reproductions is therefore desirable. Soil colors are also subject to wide variations from locality to locality. These differences are often quite characteristic of different places, and good reproductions should not distort soil colors so much as to confuse such distinctive features. Whites and grays are surprisingly rare in photographs of natural scenes, but when they occur, in clouds, or snow, or rock, or clothing, they are very sensitive indicators of the characteristic of color reproduction which is usually called *color balance.*

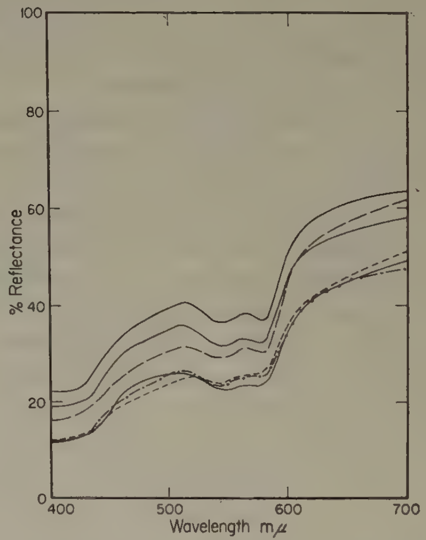

Fig. 2—Spectral reflectance curves of inside of upper arm (top) inside of forearm (second solid), outside of upper arm (long dashes), outside of forearm (short dashes), back of hand (bottom solid), and palm of man (dash-dot), showing variations of skin color produced by exposure to light and other causes. (From Edwards and Duntley.[1])

Of course, myriads of other colors also occur in natural scenes, but no one class of them is so prominent as to equal those already named, as indicators of the quality of color reproduction. Perhaps the red of lipstick, of clothing, and of flowers is the most troublesome, not because of any severe demands for accuracy, but because compromises and failures often encountered in color reproduction cause reds to appear orange. Some blue flowers, which reflect copiously the extreme red portion of the spectrum that has less visual than photographic effect in some processes, are also more troublesome than their low incidence and importance would indicate.

* Decimal classification: 770.2836×535.6. Original manuscript received by the Institute, October 20, 1953. Communication no. 1622 from the Kodak Research Labs.

† Research Labs., Eastman Kodak Co., Rochester, N. Y.

[1] E. A. Edwards and S. Q. Duntley, "The pigments and color of living human skin," *Amer. Jour. Anatomy*, vol. 65, pp. 1–33; 1939.

The Colors of Human Skin and of Their Reproduction

A thorough study of the color of human skin was made by Edwards and Duntley,[1] who determined spectrophotometric curves for many parts of the body, for many conditions of the skin, for all races, and both sexes. They identified the principal pigments and other optical phenomena responsible for the color of the skin and for its variations. Spectral reflectance curves for the cheek, forehead, and neck of a white female are shown in Fig. 1, taken from the paper of Edwards and Duntley. Curves for the arm and hand of a white male, (Fig. 2), taken from the same source, indicate the darkening or tanning effect of sunlight on the more exposed areas.[2] Fig. 3 shows spectrophotometric curves typical of the untanned skin areas for several races of men.

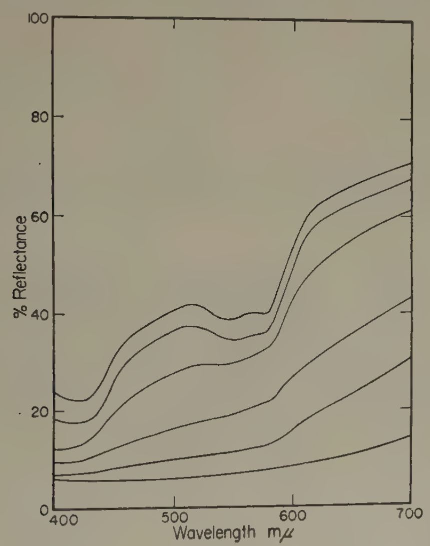

Fig. 3—Spectral reflectance curves of untanned skin, for typical men of various races. From top to bottom, white blonde, white brunette, Japanese, Hindu, mulatto, and Negro. (From Edwards and Duntley.[1])

Spectrophotometric curves for the faces of 103 subjects of all races, ranging from dark brunettes to nearly albino blondes were measured by Buck and Froelich.[3]

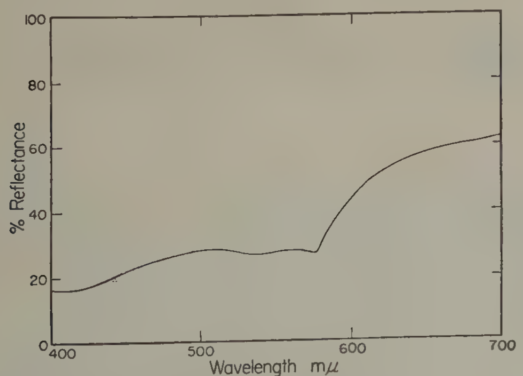

Fig. 4—Spectral reflectance average for faces of U. S. population. (From Buck and Froelich.[3])

[2] E. A. Edwards and S. Q. Duntley, "An analysis of skin pigment changes after exposure to sunlight," *Science*, vol. 90, pp. 235–237; 1939.

[3] G. B. Buck, II and H. C. Froelich, "Color characteristics of human complexions," *Illuminating Eng.*, vol. 43, pp. 27–47; 1948.

Their data are presented in Fig. 4 as a weighted average. The average curve includes measurements taken throughout the year for 51 men and 52 women within the age limits of 17 to 65, and for a wide range of complexion types. The data are weighted in accordance with United States population statistics for men and women for the various racial types, and approximately for the factors of age, hair coloring, and seasonal variations.

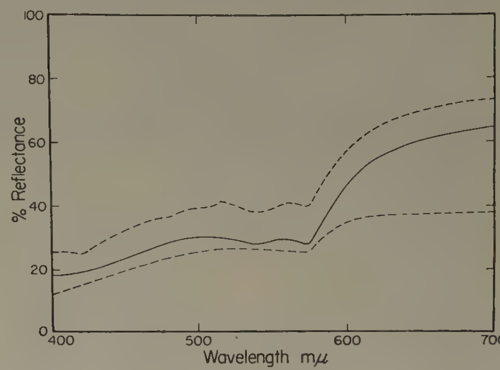

Fig. 5—Spectral reflectance curves for lightest and darkest Caucasian, and average for Caucasian faces. (From Buck and Froelich.[3])

The dotted curves in Fig. 5 show the spectral reflectance of the facial skin for the lightest and darkest individual Caucasians found. Fig. 6, also taken from the paper of Buck and Froelich, shows spectral reflectance curves for various areas of the body for an average male subject.

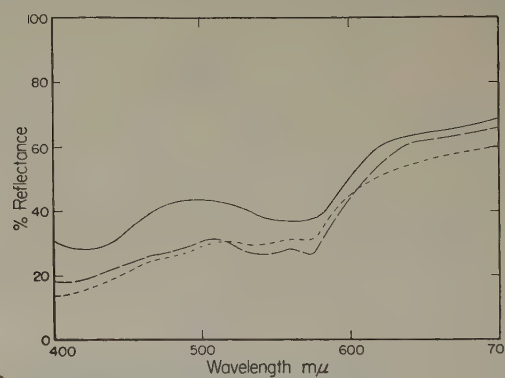

Fig. 6—Spectral reflectance curves for hip (top), face (long dashes), and upper arm (short dashes) of Caucasian male. (From Buck and Froelich.[3])

The separate, averaged curves for female and male Caucasians are shown in Fig. 7. The effect of seasonal variation in spectral reflectance is shown by the two curves in Fig. 8. The effect of age on spectral reflectance of faces is shown separately for men and women by the four curves in Fig. 9. The average spectral reflectance curves of the faces of women, with and without cosmetics, are shown in Fig. 10, following page.

Facial colors of the average Caucasian, Asiatic, and Negroid races are shown in the standard CIE chromaticity diagram in Fig. 11. Also shown are the chromaticities for various hair colors. The average spectral reflectance curves for gray, blonde, brunette, and titian hair are shown in Fig. 12, also taken from Buck and

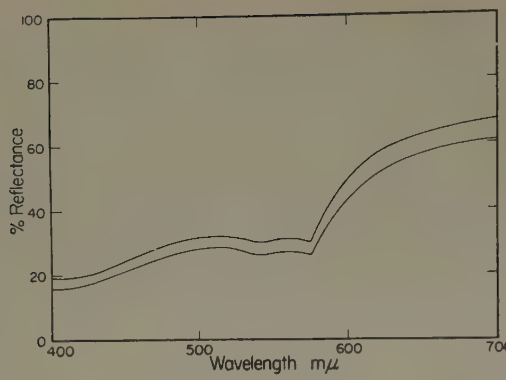

Fig. 7—Average spectral reflectance curves for faces of Caucasian women (top) and men (bottom). (From Buck and Froelich.[3])

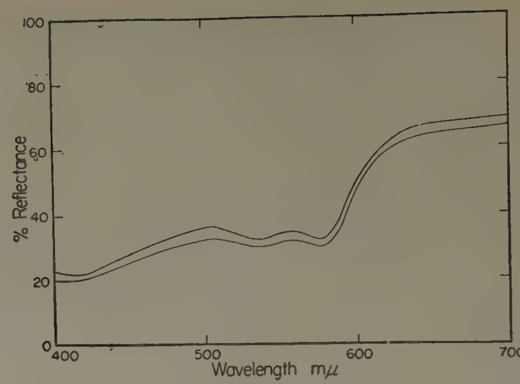

Fig. 8—Average spectral reflectance curves for faces of Caucasians (upper curve—March; lower curve—September). (From Buck and Froelich.[3])

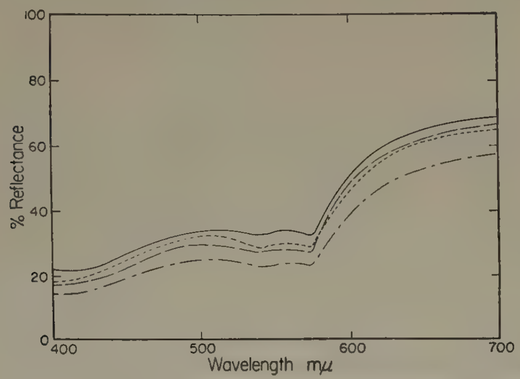

Fig. 9—Average spectral reflectance curves for women less than 30 years of age (top), women over 30 (long dashes), men less than 30 (short dashes), and men over 30 (bottom). (From Buck and Froelich.[3])

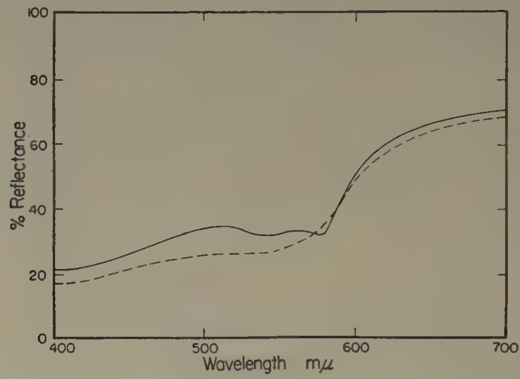

Fig. 10—Spectral reflectance curves of cheeks of Caucasian women, without cosmetics (top), and with cosmetics (bottom).

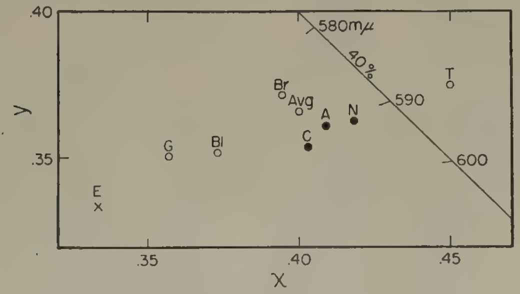

Fig. 11—Chromaticities of hair (G: gray, Bl: blonde, Br: brunette, T: titian, Avg: average) and faces (C: Caucasian, A: Asiatic, N: Negroid), based on equal-energy light source (E). (From Buck and Froelich.[3])

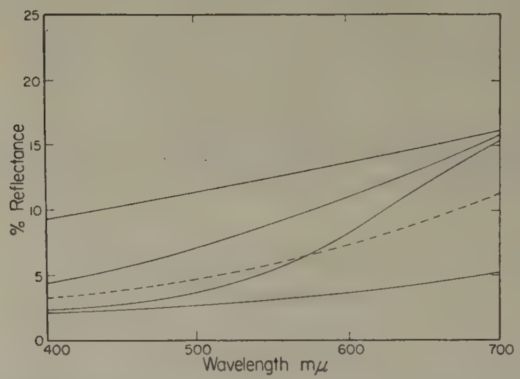

Fig. 12—Spectral reflectances of hair: gray (top), blonde (next to top), titian (middle, solid curve), average (broken curve), and brunette (bottom). (From Buck and Froelich.[3])

Froelich. Spectrophotometric curves of 53 samples of human hair, selected so as to represent the widest variation obtainable, were published by Gardner and MacAdam,[4] and a systematic classification of hair color was based on their results.

The chromaticities of a number of foreheads of young subjects recently measured in these Laboratories are represented by crosses in Fig. 13. These chromaticities were based on the assumption of CIE standard source *C*. These are essentially in agreement with the results indicated by Buck and Froelich, but indicate the variations of chromaticity to be expected from normal skin color.

Also shown by dots in Fig. 13 are the chromaticities of the reproduction of skin in 35 high-quality Kodachrome transparencies. Those transparencies were borrowed from the files of the Advertising Department of the Eastman Kodak Company, and critical examination of them by a panel of judges confirms the opinion that they all appear to be excellent color reproductions. However, it is evident from Fig. 13 that the chromaticities of many of these color reproductions are far outside the total range of natural skin colors.

The reproductions in the transparencies were measured by matching them with the field of a wide-field

[4] B. B. Gardner and D. L. MacAdam, "Colorimetric analysis of hair color," *Amer. Jour. Phys. Anthropology*, vol. 19, pp. 197–201; 1934.

binocular colorimeter[5] which was placed behind a small hole in the projection screen. The portion of the image to be measured was brought close to that hole by moving the projector. A blue filter was placed over the projection lens. This filter modified the light projected without a transparency so that it was a color match for light from CIE standard source *C*. This projection condition was used in order to make possible the direct colorimetric comparison of the colors of the reproductions with the colors in the original scenes, which were illuminated by daylight.

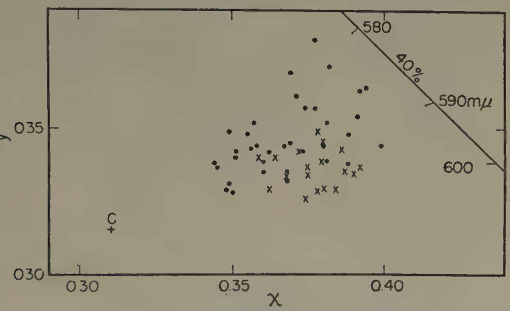

Fig. 13—Comparison of actual skin colors (x) and reproductions of skin in excellent Kodachrome transparencies (dots). Locus of 40 per cent purity is shown.

The center of the array of points in Fig. 13, representing the chromaticities of the reproductions is within the range of actual skin colors and does not seem to be very far from the center of the range of natural skin colors. This agreement of the average of the colors of the reproductions with the average of natural skin colors may be contrasted with the results which were previously reported for the preferred reproductions of skin in reflection prints and in paintings by successful artists.[6]

Fig. 14 presents additional information on the preferred reproductions of skin in reflection prints, pastel chalk portraits, and oil portraits, and Flexichrome and carbro portraits. The chromaticities of the foreheads of a number of young subjects are also shown in Fig. 14.

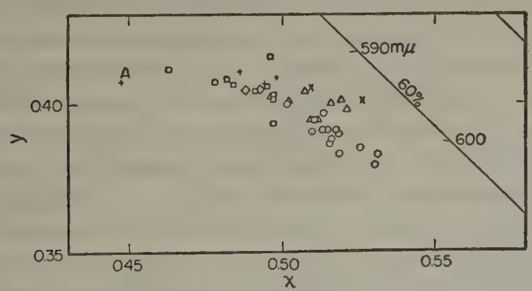

Fig. 14—Chromaticities of actual skin colors (⊙) and reproductions in pastel chalk portraits (+), oil paintings (×), dye transfer prints (△), Flexichrome portraits (□), and carbro portraits (◇).

All of the chromaticities in Fig. 14 are based on CIE standard source *A*, which has the quality of general-service tungsten lamps. This, and not daylight, was the quality of light used when the original portraits were photographed or painted, and this is the quality of the light with which they are usually viewed. Trial has shown, however, that redetermination of the chromaticities of natural skin and of the reproductions for CIE standard source *C*, artificial daylight, would not change the pattern of chromaticities in any essential respect. Fig. 14 confirms the effect previously reported that the preferred reproductions of faces in reflection prints are less red and less saturated than the natural color of human foreheads. In most of the cases represented in Fig. 14, the colors of the reproduction were not constrained by any limitations or compromises of the photographic system. The colors in the pastel and oil portraits, and in the Flexichrome prints, and to some extent in the carbro portraits, were at the complete control of the artist and presumably represented his preference and best judgment of the most satisfactory reproduction of skin color.

The practical significance of this difference between the preferred reproductions in Kodachrome transparencies and in reflection prints and paintings is difficult to assess. It has been suggested that the sense of realism is much greater when a projected transparency is viewed than when either a reflection print or a painting is viewed. It is further suggested in this connection that the heightened sense of realism demands

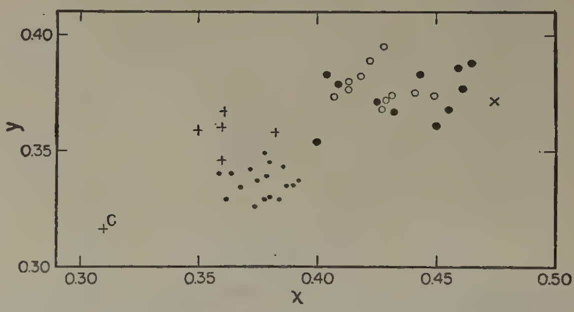

Fig. 15—Chromaticities of actual skin colors and reproductions of skin in professional motion pictures, illustrating effect of adaptation in compensating for reproduction of white: actual skin (•), good reproductions (○), fair (●), poor (×), "white" (+).

more accurate color reproduction. However, the greater spread of satisfactory reproductions of skin in Kodachrome transparencies, as indicated in Fig. 13, casts some doubt on the interpretation that transparencies require more accurate reproduction. If deviations from accurate reproduction are required for reproduction processes which do not give a highly realistic sense of the presence of the subject, then some assessment of the degree of realism in any case would appear to be important as a basis for the determination of the quality of color reproduction and for its improvement.

In Fig. 15 are shown the chromaticities of skin areas in a number of Hollywood release prints. The qualities of each of these reproductions of skin colors have been judged by a panel of judges, and the results summarized in three classes—good, fair, and poor—are shown by the open circle, the solid dots, and the cross in Fig. 15. These chromaticities were determined by use of the projection colorimeter previously described and by use of the daylight conversion filter on the projector lens. The

[5] D. L. MacAdam, "Loci of constant hue and brightness determined with various surrounding colors," *Jour. Opt. Soc. Amer.*, vol. 40, pp. 589–595; 1950.

[6] D. L. MacAdam, "Quality of color reproduction," Proc. I.R.E., vol. 39, pp. 468–485; May, 1951.

chromaticities of the foreheads of a group of subjects are also shown by small dots in Fig. 15.

At first glance, it appears that all the satisfactory reproductions have purities about twice as great as real skin colors. However, measurements of a few white objects in the transparencies reveal the fact that these are reproduced as quite distinctly yellow, compared to the color of the light from the projector. The chromaticities with which white objects are reproduced in a number of these transparencies are shown by the plus signs in Fig. 15. If the average of the points representing the reproductions of white is taken as the reference standard for the determination of purity,[7] then the purities of the reproductions of faces are not, on the average, appreciably greater than the average purity of the original skin colors determined on the basis of CIE standard source C as the reference standard. Such a change of basis corresponds to and is justified by the effects of visual adaptation which, in the absence of conflicting clues concerning the quality of white, causes observers to accept the reproduction of white.

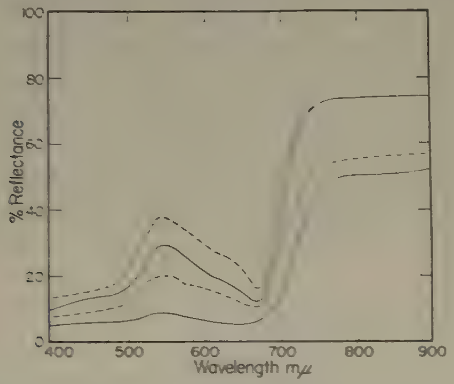

Fig. 16—Spectral reflectances of green leaves. From top to bottom: back and front of tulip leaf; back and front of ivy leaf. (From Nickerson, Kelly, and Stultz.[8])

Similarly, when the average reproduction of white is taken as the reference standard, the dominant wavelength[7] of the average reproduction of skin in the professional motion-picture films is close to the dominant wavelength of the average of real skin colors determined on the basis of CIE standard source C as reference standard. These results confirm those indicated in Fig. 13 for Kodachrome, in that the dominant wavelength and purity (relative to the reproduction of white) of the average reproduction of skin are nearly identical with the dominant wavelength and purity of average skin. Fig. 15 also indicates that the range of satisfactory reproductions of skin greatly exceeds the range of chromaticities of natural skin.

The Colors and Reproductions of Foliage and Sky

Spectrophotometric curves of foliage have been determined by Nickerson, Kelly, and Stultz.[8] A few of their results are shown in Fig. 16. The chromaticities of a number of foliage samples are shown on an enlarged section of the CIE diagram for standard source C in Fig. 17. This diagram was taken from a paper by Hendley and Hecht.[9] The chromaticities of the reproductions of foliage in a few Kodachrome transparencies are shown in Fig. 18, in which the curve drawn by Hendley and Hecht, enclosing their foliage colors, is also included.

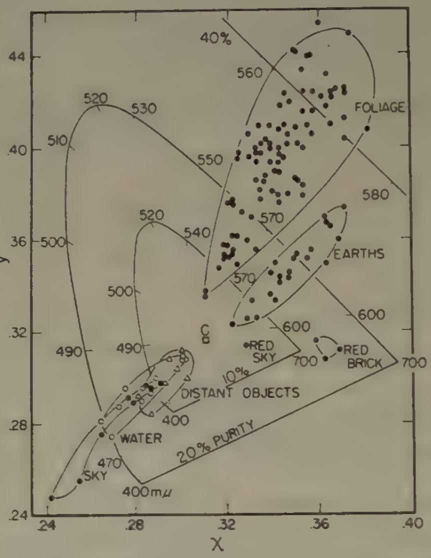

Fig. 17—Chromaticities of leaves, earths, sky, water, brick, and distant objects in daylight. (From Hendley and Hecht.[9])

Reproductions of foliage in three of the professional motion pictures are also shown, by plus signs, in Fig. 18. Those reproductions appear to be well within the range indicated by the data of Hendley and Hecht. Further work is needed, of course, to establish the complete facts in this case, but tentatively the gamut of chromaticity shown by Hendley and Hecht may be taken as an indication of the extent of the variations to be expected in natural foliage colors and as an indication of the chromaticities with which they should be reproduced.

Fig. 17 also indicates the chromaticities Hendley and Hecht found for blue sky. The reproductions of blue sky in a number of Kodachrome transparencies are shown in Fig. 19, on which is also indicated the outline with which Hendley and Hecht enclosed all the sky colors which they observed. Since, in Kodachrome transparencies, white objects are reproduced by nearly nonselective areas of the film, so that observers are adapted to the chromaticity of the filtered projector light, the points shown for the Kodachrome sky colors should be directly comparable to the outline of sky colors reproduced by Hendley and Hecht. It is apparent that some of the reproductions have appreciably greater purity than any of the sky colors observed. Most of the higher-purity reproductions of blue sky also appear to be somewhat more violet or less greenish-blue than the actual sky colors observed by Hendley and Hecht.

[7] "Standards on television: definitions of color terms, part 1," Proc. I.R.E., vol. 41, pp. 344–347; March, 1953.

[8] D. Nickerson, K. L. Kelly, and K. S. Stultz, "Color of soils," Jour. Opt. Soc. Amer., vol. 35, pp. 297–300; 1945.

[9] C. D. Hendley and S. Hecht, "The colors of natural objects and terrains, and their relation to visual color deficiency," Jour. Opt. Soc. Amer., vol. 39, pp. 870–873; 1949.

The Kodachrome transparencies were submitted to a panel of judges who were asked to record their assessments of the qualities of the reproductions of the sky colors. The results are indicated in Fig. 19 by open circles which indicate the reproductions of sky which were judged to be good by the consensus of the panel of observers. Plus marks indicate the chromaticities of the reproductions which were rated fair, and small points indicate the reproductions which were rated poor. The trend of these results is such as to indicate that reproductions more nearly matching sky colors are preferred to reproductions which have higher purity or more violet hues.

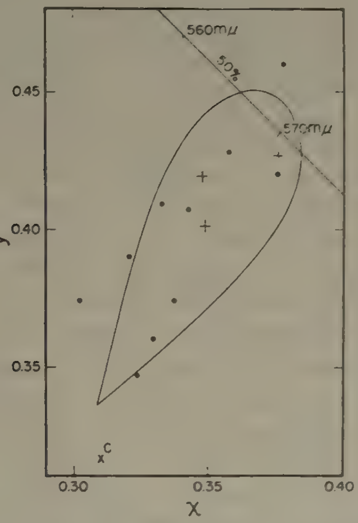

Fig. 18—Chromaticities of Kodachrome and professional motion-picture reproductions of foliage, compared with gamut of foliage colors found in nature: Kodachrome (dots), professional motion pictures (+). Locus of 40 per cent purity is shown.

Reproductions of sky in a few of the professional motion pictures are shown by crosses in Fig. 19. These chromaticities are close to the range of real sky colors shown in Fig. 17. However, relative to the average reproduction of white, on which the adaptation of the audience is based, the reproductions are somewhat greener and more saturated than real sky colors.

Fig. 17 also indicates the gamut of chromaticity Hendley and Hecht found for bodies of water in natural scenes. Very few reproductions of such colors have been measured. Most of the reproductions, however, fell somewhat outside the gamut indicated by Hendley and Hecht, in essentially the same direction and magnitude with which the reproductions of sky differed from their observations.

The gamut of soil colors found by Hendley and Hecht is also indicated in Fig. 17. The results of Nickerson, Kelly, and Stultz[8] indicate a somewhat broader gamut of soil colors. Hendley and Hecht account for this difference by pointing out that they did not make a thorough search for brilliantly colored soils. Also, most of their observations were of terrains seen from a distance, whereas those of Nickerson, Kelly, and Stultz were of samples of soil placed in a spectrophotometer.

The influence of atmospheric scattering on the colors of distant objects has been discussed by Middleton.[10] He calculated the color changes to be expected with increasing distance of observation. The chromaticity which he predicted that all distant objects would approach was very closely confirmed by the direct observations of Hendley and Hecht. The chromaticities of some distant objects are shown by triangles in Fig. 17. The range of chromaticities exhibited by red brick is also shown in Fig. 17, and the chromaticity of red sky is indicated by a point in that figure.

Hendley and Hecht conclude that the outstanding characteristic of terrain colors is their low purity. Only a few leaves, viewed at close range, had a purity of more than 40 per cent. Furthermore, they found that objects quickly lose purity with increasing distance of observation, so that even in the clearest weather encountered, no terrain over three and one-half miles away had a purity of over 11 per cent.

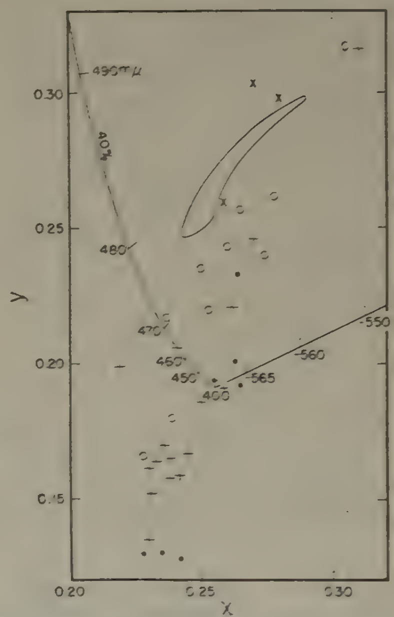

Fig. 19—Chromaticities of Kodachrome and professional motion-picture reproductions of sky with gamut of sky colors found in natural scenes (outlined): good Kodachrome reproductions (○), fair (+), poor (•), professional motion pictures (×). Locus of 40 per cent purity is shown.

Hendley and Hecht also made an autumn survey of the colors of foliage. Their results are shown in Fig. 20 on the following page. Most of the samples were of deciduous trees. Somewhat higher purities are indicated by the chromaticities in this figure than for colors of summer terrains.

The ranges of colors to be expected in clothing and accessories, in both daylight and artificial light, are indicated in an extensive report on the standard colors of the Textile Color Card Association.[11]

[10] W. E. K. Middleton, "The colors of distant objects," *Jour. Opt. Soc. Amer.*, vol. 40, pp. 373–376; 1950.

[11] G. Reimann, D. B. Judd, and H. J. Keegan, "Spectrophotometric and colorimetric determination of the colors of the TCCA standard color cards," *Jour. Opt. Soc. Amer.*, vol. 36, pp. 128–159; 1946.

Color Balance

As previously mentioned, observers of color transparencies tend quickly to become adapted to the reproductions of whites and grays, so that even when, as in the case of professional motion pictures, these reproductions exhibit quite appreciable saturation when the film itself is examined, the projected images of white and gray objects almost always appear white and gray.

Extreme variations of the reproductions of white and gray from chromaticities of zero purity may be noticed, especially if the chromaticities of such reproductions differ from scene to scene and are viewed in quick succession. Such variations are, of course, accompanied by similar variations of the colors with which other objects are reproduced, and when noticed, such variations in the over-all color of a picture are customarily referred to as variations of balance.[12]

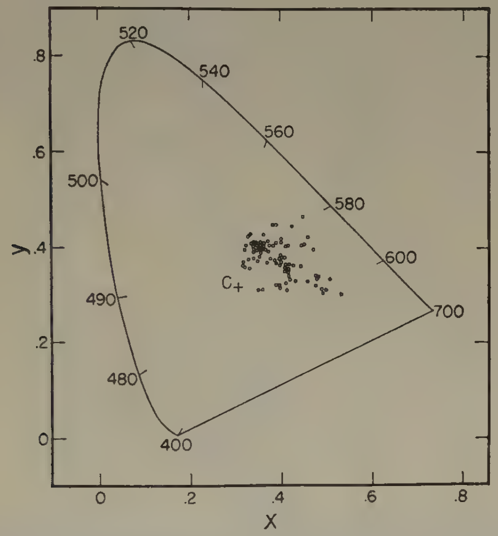

Fig. 20—Chromaticities of autumn foliage. (From Hendley and Hecht.[9])

Variations of color balance may arise from many causes, such as: mismatching of the spectral sensitivities with which the color separations are made; use of a light source of improper quality in making the photographs; the effects of age or temperature or other conditions of storage of exposed or unexposed film; variations in many stages of the processing; and the effects of age and unsuitable storage conditions of the processed films. Deviations of each of these factors from established standards are sometimes called *variations of balance*, but the term *balance* will be used here to refer exclusively to the end-effect, the presence or absence of an over-all distortion of color as evidenced by a more or less consistent displacement of all reproductions toward a single color.

Color-balance distortions are most easily seen and measured in the reproductions of white and gray objects. But such objects do not appear in all pictures. As a matter of fact, white and gray objects are absent from a surprisingly large proportion of pictures of natural scenes. Whether or not white and gray objects are evident in the scene, variations of color balance are nevertheless quite easily noticeable and, particularly in the case of reflection prints, they are quite objectionable. Even in the case of transparencies, improper color balance is undesirable: in motion pictures, because of fluctuation from scene to scene; in still pictures, because the films themselves are frequently examined directly, so that the eye cannot become adapted to the particular balance; in general, because variations of color balance have an important secondary effect on luminances with which colors of high purity are reproduced.

A number of ways of measuring color balance have been suggested and used. Perhaps the simplest and most universally applicable criterion, although not necessarily the one most indicative of observer judgments of color balance, is the measurement of the chromaticities of the reproductions of white and neutral gray test objects, deliberately placed in the scene. The chromaticity of a medium gray object, having a reflectance from 20 to 30 per cent, appears to be more nearly indicative of the color balance than the reproductions of white, or light gray, or dark gray, or black. Of course, if there are gross differences between the chromaticities of the reproductions of light, medium, and dark grays, the quality of the picture suffers. Such conditions are usually given particular names, such as *pink toe* and *blue shoulder*, and strenuous efforts are made to eliminate such conditions. In cases in which such phenomena are not prominent, and in which light, medium, and dark grays all give fairly concordant indications of color balance, then medium grays provide the single measurable quality which correlates most directly with judgments of the color balance of the entire picture.

In Fig. 21 are shown the chromaticities of the reproductions of a gray suit in a number of prints of a single portrait. This set of prints was made especially for this investigation, and the color variations indicated in Fig. 21 were introduced deliberately. The prints which have such wide but evenly distributed variations of color balance, and which appear all of very nearly the same contrast and over-all density, were prepared by Mr. C. D. Edgett and his coworkers in these Laboratories. Such preparations, requiring meticulous attention to accuracy and detail, are essential for psychophysical studies of the quality of color reproduction by any process, whether photographic or nonphotographic.

Adjacent to the circle in Fig. 21 representing the chromaticity of the suit in each reproduction is indicated the score derived from a set of complete paired comparisons by a panel of five judges, each of whom gave comparisons of high consistency. The reflection prints were judged while illuminated by light from tungsten incandescent-filament lamps filtered so as to give a color temperature of about 4,000 degrees Kelvin.

[12] R. M. Evans, W. T. Hanson, Jr., and W. L. Brewer, "Principles of Color Photography," J. Wiley and Sons, New York, N. Y., p. 154; 1953.

The reproductions were measured spectrophotometrically, and the chromaticities indicated in Fig. 21 were calculated on the assumption that the light source was a blackbody at the temperature of 4,000 degrees Kelvin. A plus sign just left of center in Fig. 21 indicates the chromaticity of the assumed 4,000-degree K source. The two prints in which the chromaticities of the suit were closest to that of the light source were awarded the highest scores by the panel of judges. Scores for the other reproductions decreased nearly in accordance with the increase of distances of the points representing their chromaticities from chromaticity of the light source.

These results appear to indicate that, for high-quality reflection prints, the reproductions of medium gray should have nearly the chromaticity of the light with which the print is illuminated. This finding may be contrasted with that previously reported and confirmed above that the preferred reproductions of faces in reflection prints do not have chromaticities equivalent to those of the original subjects.

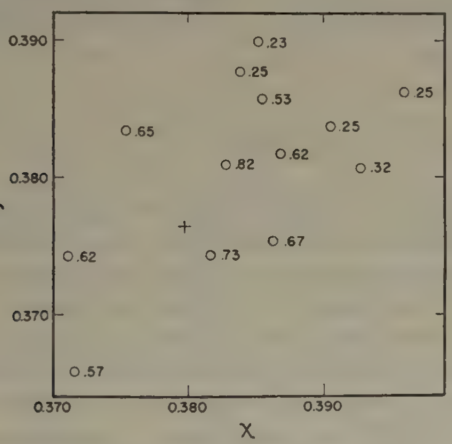

Fig. 21—Chromaticities of suit reproductions with corresponding judgment scores.

Paired-Comparison Method

A brief discussion of several judgment methods seems to be appropriate at this place. Three principal kinds of judgment methods have been used in the study of the quality of color reproductions. The original report of the significant difference between preferred color reproduction of faces and the skin colors of the original subjects was based on the *rating method*. In this, a large number of prints are examined, one after another, and each individual print is merely accepted or rejected. In some modifications of this method, a response indicating "doubtful" is permitted. In more elaborate variations of this method, the prints may be sorted into a larger number of categories, such as excellent, good, fair, poor, and very poor.

In the second general type of judgment method, all the prints to be judged are presented and examined simultaneously. The judge is asked to arrange them in a sequence, from best through progressively less satisfactory to the poorest. This is called the *ranking method*. Many methods of computing the results have been applied to the rankings provided by judges. For instance, the prints in the order produced by the judges have been assigned ordinal numbers, and then the ordinal numbers assigned to each print by a number of judges may be averaged. The averages are then taken to indicate the relative merits of the prints in a series according to the judgment of the whole group of observers. A prominent use of this method was in the extensive study of the quality of tone reproduction in monochrome prints,[13] on which the American Standards Association fractional-gradient criterion for the determination of speeds of negative materials was based. This method has been used in the study of color reproductions, but judges find it rather troublesome in cases in which the differences between prints evidently arise from a number of simultaneous but different variables. The results, when obtained, are usually quite consistent with the rating methods.

In the method of *paired comparison*, which was used in obtaining the results shown in Fig. 21, only two prints at a time are exhibited to the observer. He is asked merely to indicate his preference. If the group of prints being judged is not more than 15 in number, a complete set of paired comparisons can be made. If a larger number of prints is involved, the number of comparisons necessary for a complete paired-comparison judgment becomes excessive. The observer tends to become tired, and his results deteriorate as his criterion of excellence changes and as his attention wanders. The number of comparisons can be reduced by omitting those for which the response is known with virtual certainty. Other pairs can also be omitted from comparisons in order to reduce their number to a feasible total. However, the treatment of the results of incomplete paired comparisons is still under discussion. Several methods have been advocated and used, but none has been satisfactory. Further studies are known to be in progress, and it is expected that improved methods for handling the data of incomplete paired comparisons will be published shortly.[14] However, these will almost certainly involve the use of powerful high-speed electronic computers. Until such methods are available and their use is established, it seems advisable to limit the number of samples to be compared to a small number. A maximum of 15 is suggested. Results are then easily determined by established methods.[15]

A unique advantage of the paired-comparison method is that it provides a measure of the consistency of the

[13] L. A. Jones, "The evaluation of negative film speeds in terms of print quality," *Jour. Frank. Inst.*, vol. 227, pp. 297–354, 497–544; 1939.

[14] M. G. Kendall, "The Advanced Theory of Statistics," vol. I, C. Griffin and Co. Ltd., London, England; 1948.

[15] J. H. Morrissey, "Application of the least-squares criterion to the analysis of response differences from incomplete paired comparisons," (abstract) Proceedings of the 38th Annual Meeting, *Jour. Opt. Soc. Amer.*, vol. 43; December, 1953.

judgments of each individual observer and also an index of agreement between the judgments of a whole group of observers.

The method of paired comparisons appears to be especially suitable when the samples to be compared are subject to continuous variation and when they cannot be preserved in permanent form. This seems to be typical of color television.

For the study of the quality of reproduction in color television, the method of paired comparisons would require two nearly equivalent receivers and duplicate transmission equipment following the site of the adjustments under investigation. The pairs of reproductions to be compared could then be presented, side by side, by adjusting the appropriate controls on the transmission or receiving equipment. A few sets of values of the parameters governing the quality under investigation could be selected. If complete paired comparisons are to be made, the number of these sets should not exceed 15. The schedule of presentation and the use of the selected set of reproduction variables could and should be such as to eliminate small possible differences between the two receivers. Analysis of the results of such comparisons may be expected to determine unambiguously the optimum values of each of the reproduction variables, the tolerance on each, and the possible dependence of each on the values of other parameters in the reproduction system. Ultimately, it is to be hoped that the chromaticities of the reproductions can be measured directly and that the results of paired-comparison judgments can be presented directly in terms of the reproduced chromaticities, as in Fig. 21.

Brightness Modification Proposals for Televising Color Film*

W. L. BREWER†, J. H. LADD†, AND J. E. PINNEY†

Summary—**Color photographic film will undoubtedly provide much of the program material for color television. If film is to be displayed to its greatest advantage, the color gamuts of film and television must be effectively evaluated. Exact colorimetric reproduction of natural scenes is neither possible nor necessarily desirable with live television or with projected motion pictures. In the present state of the art, color television reproduced luminance ranges are limited. Better televised film will result if: (1) the effective scene luminance range is modified, either in the film or in the television system, to conform to that available on the kinescope, and (2) kinescope reproductions of film colors are made lighter with increasing saturations. In principle this color-dependent brightness compensation can be accomplished by several methods. One proposed method would require insertion of new equipment in the television film chain. Alternative suggested methods require only modifications of existing television film chain equipment.**

Introduction

SUBSTANTIAL PORTIONS of the program and advertising material for color television undoubtedly will come from color photographic film, just as much material for monochrome television comes from black-and-white film. The factors favoring film utilization are essentially the same for color as for monochrome. Film programs may be prepared at the times and locations most convenient for their preparations and then shown at times most opportune for their presentations. Repeat performances are readily available and a convenient means is provided for meeting the needs of smaller television stations. Also, films can be comprehensively previewed and edited, thus making possible highly compact and effective end results.

Despite its obvious desirability, film utilization in color television will prove satisfactory if certain difficulties associated with the combining of these two different types of media are overcome. One major problem arises because, in the present state of the art, the output brightness or luminance range of the color television system is very much limited. Color film pictures normally have a relatively large range of luminances. The luminance range in film might be reduced but, partially because of basic limitations in the dye systems available for films and partially because good color picture reproduction requires a fairly high luminance range, this range cannot be greatly reduced. Televised color pictures would show improvement for both live and film pickup if the television system luminance range could be extended. Without decided changes in either film or color television system characteristics, however, improvement in the appearance of televised film can probably be obtained by altering the color film record signals in such a way that the transmitted film picture more closely fits the color gamut obtainable from the television system.

The nature of the luminance problem can probably be best understood if consideration is first given to the chromatic and brightness characteristics of scenes and their reproductions on television and film.

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† Color Technology Div., Eastman Kodak Co., Rochester, N. Y.

Scene Reflectance

Objects as normally viewed will appear as white if they have essentially uniform reflectance through the visible spectrum and the reflectance is as high as about 0.8. The reflectance value designated as white is by no means absolute and is dependent upon the reflectances of other objects in the field of view, the illumination conditions, and a variety of other factors pertaining to the viewing conditions. As a rough indication of the order of magnitude of the minimum required reflectance, however, 0.8 is probably a reasonable figure. The normal reflectance of the chip of Munsell Value 9, for example, is 0.79;[1] that of the chip in the achromatic series of highest reflectance in the Ostwald system is 0.89.[2] Both these chips will normally be seen as white in a variety of forms of daylight or in any of a wide variety of artificial illuminants. The requirement of uniform reflectance in the visible spectrum is sufficient, but not necessary. In a given illumination any object color may exist in an unlimited number of metameric forms.

Objects with reflectances throughout the visible spectrum of about 0.04 or less will usually be seen as black. As for white objects, the reflectance limit is not absolute, depending a great deal on the viewing conditions. The chip in the Ostwald system which is considered to be acceptable as black has a nominal reflectance of 0.035.[2] The chip of Munsell Value 1.3, reflectance 0.017, has been indicated in some notations as black,[3] but those of Munsell Value as high as 3.0, reflectance 0.065, appear reasonably black, particularly if side-by-side comparisons with darker objects are not available. For reflectance values of the order of magnitude given, the reflectance should be spectrally uniform or, under the viewing illumination, be metameric to an object with a uniform reflectance.

Fig. 1 provides a rough indication of the relationship existing between visual lightness and object reflectance. The abscissa axis is scaled according to equal steps in lightness differences as determined by actual observer judgments.[4,5] The ordinate scale on the right is per cent reflectance on a logarithmic scale. The scale on the left-hand side is visual density. Here density is defined as the negative logarithm of the reflectance or, in the case of transmitting materials, as the negative logarithm of the transmittance. Zero density represents 100 per cent reflectance, with density increasing with decrease in reflectance.

The general regions of blacks, grays, and whites are indicated along the bottom of the figure. Sharp demarkation lines between blacks and grays or between grays and whites do not exist.

Accepting as approximations a reflectance value of 0.8 for white objects and a reflectance value of 0.04 for black objects, the luminance range of a scene from white to black would be 20 to 1, *if* the scene is uniformly illuminated.

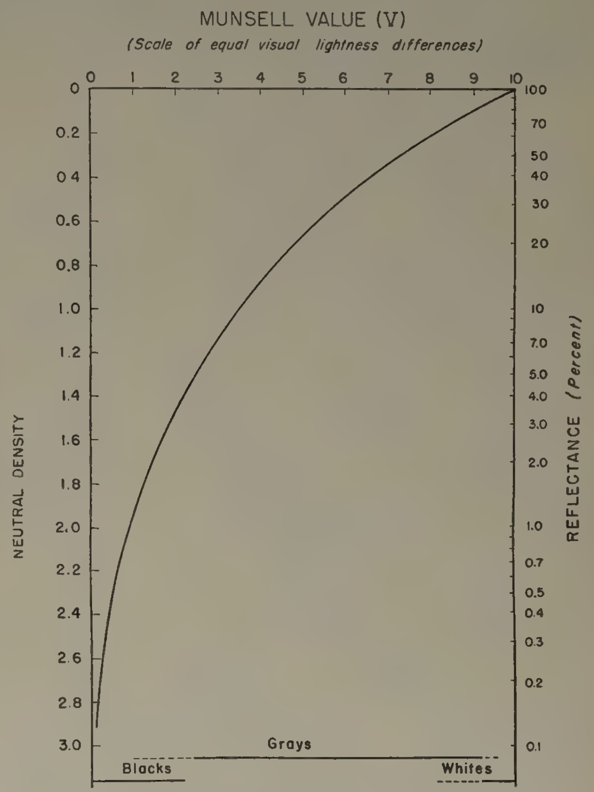

Fig. 1—Reflection density versus scale of equal visual lightness differences for neutral objects in Munsell Renotation.[1]

Scene Illuminance and Luminance

The "illuminance" of an object refers to the light falling on it, hence is independent of the reflectance or transmittance of the object. The "luminance" of an object as viewed from a particular position refers to the light reaching that position from the object. The luminance of an opaque object is dependent upon both illuminance of the object and reflectance of the object.

It is of particular interest and importance to note that the intensity and spectral characteristics of the prevailing illumination can change quite markedly without altering the recognition of white objects as white objects and black objects as black objects. Objects are usually viewed in nonuniform illumination. If there is a small source of illumination the intensity of the light falling on objects decreases with increasing distance from this source. Frequently some objects shadow others, those shadowed receiving only indirect illumination. Despite these variations and despite the variations in the intensity of light falling on the objects, within rather wide limits, white, gray, and black objects tend largely to

[1] S. M. Newhall, D. Nickerson, and D. B. Judd, "Final report of the O.S.A. subcommittee on the spacing of the Munsell colors," *Jour. Opt. Soc. Amer.*, vol. 33, p. 406; July, 1943.

[2] C. E. Foss, D. Nickerson, and W. C. Granville, "Analysis of the Ostwald color system," *Jour. Opt. Soc. Amer.*, vol. 34, p. 365; July, 1944.

[3] D. Nickerson and S. M. Newhall, "Central notations for ISCC-NBS color names," *Jour. Opt. Soc. Amer.*, vol. 31, p. 589; Sept., 1941.

[4] S. M. Newhall, "Preliminary report of the O.S.A. subcommittee on the spacing of the Munsell colors," *Jour. Opt. So. Amer.*, vol. 30, pp. 617–645; Dec., 1940.

[5] S. M. Newhall, D. Nickerson, and D. B. Judd, *loc. cit.*, pp. 406, 416–417.

retain their relative lightness identities. It is possible to place two white objects within the same scene in different illuminations, so that the actual object luminance ratios are as high as 100 and yet have both surfaces readily recognizable as white.[6] Extreme illumination ratios such as 100 are seldom encountered and are not of interest with respect to photographic or television reproduction. In nature, illuminance ratios of 4 to 30 are common, with the average slightly less than 10.

Jones and Condit[7] have reported that outdoor scenes have luminance ratios extending from 27 to 760, with an average of about 160.

Luminance Reproduction

For faithful tonal reproduction a luminance output range of at least several hundred would be required, along with a linear relationship between luminance input and luminance output for the system. Neither television nor photography achieve these ideals. The output luminance ratio of the image in monochrome television typically has a maximum value in the vicinity of 100. This maximum would apply only between large areas in the image. The maximum value of the kinescope luminance ratio between small adjacent areas is probably nearer 20. Halation effects, indirect optical excitation of phosphor grains by adjacent grains, and stray illumination, tend to give much smaller contrast ratios for small adjacent areas than for large areas.[8]

The luminance transfer characteristic curve of a television system is plotted with scene luminance (or more properly, television camera illuminance) on a logarithmic scale as abscissa and kinescope luminance on a logarithmic scale as ordinate. The ordinate distance from minimum to maximum kinescope luminance is the kinescope luminance range. The corresponding abscissa distance is the portion of the scene luminance range which can be reproduced, and is here defined as the "scene contrast range" of the television system. It represents a capability of the television system and is independent of the actual scene luminance range present. The ratio of the logarithm of kinescope luminance range to the logarithm of scene contrast range is here defined as the "transfer gradient." If the transfer gradient is greater than unity, the scene contrast range for color television system is smaller than the kinescope luminance range. These relationships are illustrated in Fig. 14.

The luminance transfer characteristic curve for a photographic film system may be represented similarly. Such a curve for one common black-and-white motion picture film system is illustrated in Fig. 2. The film transfer gradient is only about 0.9. The scene contrast range for photographic film is larger than that of television. The curve shown in Fig. 2 was derived from two curves, the first giving the transmittance of the camera negative as a function of the illuminance of light incident on the negative from the scene, and the second the transmittance of the positive film as a function of the luminance of light transmitted by the negative. The curve applies best in dealing with large areas. Small-area effects are encountered in the film which cause departures from these curves, but they are not so pronounced as in television.

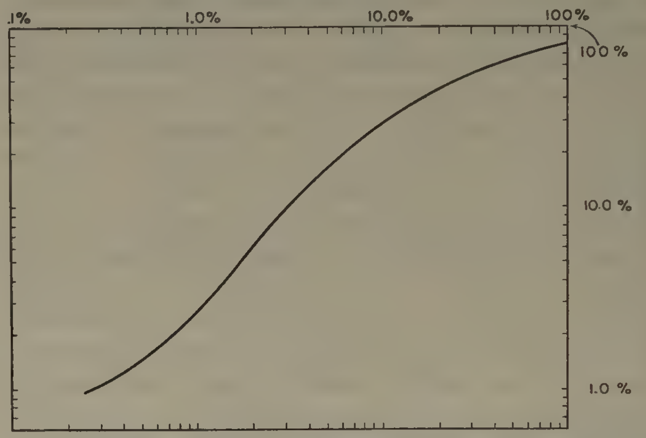

Fig. 2—Luminance transfer characteristic of a black-and-white motion picture film system involving a negative camera film and a positive release print film.

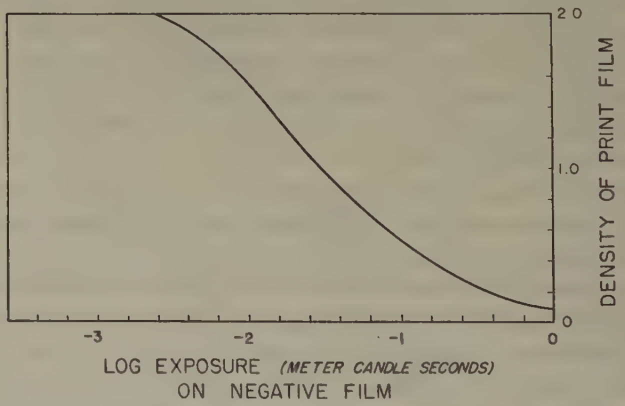

Fig. 3—Curve of Fig. 2 represented as a print through curve, in conformity with usual photographic practice.

In photographic work the normal way of representing transfer characteristics is in terms of optical density on a linear scale as a function of exposure on a logarithmic scale. The curve of Fig. 2 has been replotted in Fig. 3 in these terms. This curve is referred to as the "print through curve" of the combination of camera and print films. The plot of density versus logarithm of exposure for a single film is called the "H and D curve" after its originators, F. Hurter and V. C. Driffield.[9]

[6] R. M. Evans, "Visual processes and color photography," *Jour. Opt. Soc. Amer.*, vol. 33, pp. 579–614; Nov., 1943.

[7] L. A. Jones and H. R. Condit, "The brightness scale of exterior scenes and the computation of correct photographic exposure," *Jour. Opt. Soc. Amer.*, vol. 31, pp. 651–671; Nov., 1941.

[8] D. G. Fink, "Television Engineering," McGraw-Hill Book Company, Inc., New York, N. Y., pp. 133–135; 1952.

[9] F. Hurter and V. C. Driffield, "Photo-chemical investigations and a new method of determination of the sensitiveness of photographic plates," *Jour. Soc. Chem. Ind.*, vol. 9, pp. 455–469; 1890.

Present indications are that, because of increased equipment complexities, the maximum kinescope luminance range will be less for color television than for monochrome. The transfer gradient is apt to be somethat less for color because "gamma correction" is provided in color television. In Fig. 4 are shown curves of luminance transfer characteristics measured at two television studios.[10] Curve A shows a scene contrast range of about 20 and a kinescope luminance range of about 50. The transfer gradient is approximately 1.2. There was no ambient illumination at the receiver when these measurements were made. Curve B represents measurements taken at another studio with some ambient room illumination. In this case the kinescope luminance range is reduced to about 16.

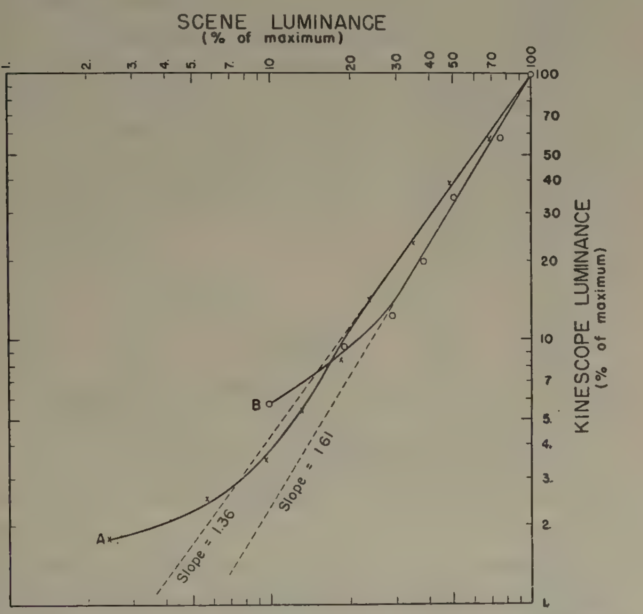

Fig. 4—Color television luminance transfer characteristics measured at two different studios, (A) with no ambient room illumination and (B) with ambient room illumination.

H and D curves representing transfer characteristics for a color photographic process are shown in Fig. 5. Three curves are included. One curve pertains to the concentration of cyan dye as a function of the logarithm of exposure. A second pertains to the magenta dye, and a third to the yellow dye. The exposures for the film strips from which these curves were derived were made to the illuminant for which the product is balanced through a silver, neutral-density, step tablet. Superposition of the three curves at any point indicates a "neutral color." This means that light transmitted by the film would have the same chromaticity as the viewing illuminant. The curves have an output range of about 460 in the film record, and a transfer gradient of approximately 1.2. Curves for other photographic processes would differ from these, but almost all color photographic processes have density ranges of at least 2.5, and frequently exceed 3.0. The transfer gradients are almost always greater than 1.0. Gradients in the vicinity of 1.2 to 1.4 are fairly typical.

[10] RCA and NBC "Petition of Radio Corporation of America and National Broadcasting Company, Inc., for approval of color standards for the RCA Color Television System," pp. 376–377; before Federal Communication Commission, Washington, D. C., June 25, 1953.

The curves for Fig. 5 are for a reversal-type process, that is, one in which the film originally exposed is developed directly into a positive image for viewing. As in the case of black-and-white photography, color photographic systems exist in which the camera film is developed to a negative from which a positive print is made. The negative material normally has a low gradient, the print a relatively high one. The print through curves for most negative-positive color photographic systems would not differ greatly from reversal film in Fig. 5.

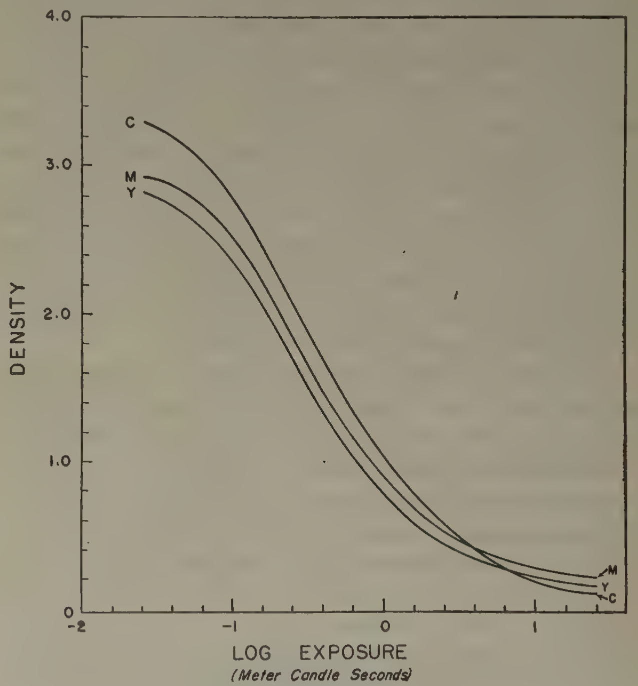

Fig. 5—Cyan (C), magenta (M), and yellow (Y) dye H and D curves for a reversal color process.

Neither color television nor color photographic systems are able to reproduce the full luminance ranges of many natural scenes. Such reproductions are not necessary, however, and probably are not desirable. If the scene is uniformly illuminated and if specular highlights are neglected, a scene contrast range of 20 and a luminance output range of 20 in the reproducing system would probably be sufficient. The requirement for a greater luminance output range in the reproducing system comes about because of non-uniform illumination within the scene to be reproduced. In direct observation of a scene there is a tendency to see objects in their true lightness or reflectance relationships regardless of fairly extreme nonuniformities in illumination. The same constancy effects operate for the reproduced scene, but to a lesser extent. A white, in a region of relatively low illumination in an original scene, will normally be perceived as a white. If reproduced on film or television, however, this same area would likely be seen as a gray.

If objects are to maintain their true lightness appearances in reproductions it is necessary that the scene illuminance ratio be kept much lower than is normally encountered in nature.

Common practice in motion picture work is to limit the scene illuminance ratio to about 4. Because of its more limited scene contrast range, recommendations for television are that the scene illuminance ratio should seldom exceed 2.[11] By employing such limitations it is possible to restrict the luminance range of the subject material to that which is reproducible in the photographic or television system.

Scene Chromatic Properties

Objects in nature which differ in color from that of the prevailing illumination normally do so because they selectively absorb the incident radiant energy. They are highly chromatic, or saturated, if they absorb relatively large amounts of radiant energy from certain portions of the visible spectrum as compared to other portions. The greater the absorption of an object the darker it is and the higher its density. Consequently, there is a relationship between the maximum possible luminous reflectance of any object color and its chromaticity. As object colors of any given hue become more saturated, the maximum possible lightness is reduced.

MacAdam has developed the theory of maximum excitation purity as a function of luminous reflectance and has established contour lines on chromaticity charts indicating these limits.[12,13] MacAdam's treatment presumes objects which either fully reflect or fully absorb light in each portion of the spectrum. No objects in nature exist with these characteristics. Consequently, they have much lower luminous reflectances than those indicated by the MacAdam limits. It is important to note, however, that there are both theoretical and practical limitations on the luminous reflectances obtainable for objects of any given chromaticity.

Chromatic Reproduction Theory

In color television the colors of an additive display are commonly obtained through excitations of a red, a green, and a blue phosphor. The three phosphors can be excited essentially independently of each other, thus making possible saturated colors of relatively high luminances. The maximum obtainable luminance for any hue decreases with increasing saturation, but the rate of decrease is relatively small as compared to natural objects. The maximum luminances for some chromaticities, relative to the white of the system, approaches the theoretical limits.

No subtractive color photographic process exists having a maximum luminance characteristic, as a function of chromaticity, similar to that of the television receiver. A close approximation to the television system could be obtained if a process were available having dyes with uniform absorptions in limited spectral regions and no absorptions elsewhere. No such dyes actually exist but hypothetical dyes with these spectral characteristics are sometimes employed in theoretical work on color reproduction theory. They are commonly called block dyes. Fig. 6 gives the chromaticity gamuts obtainable

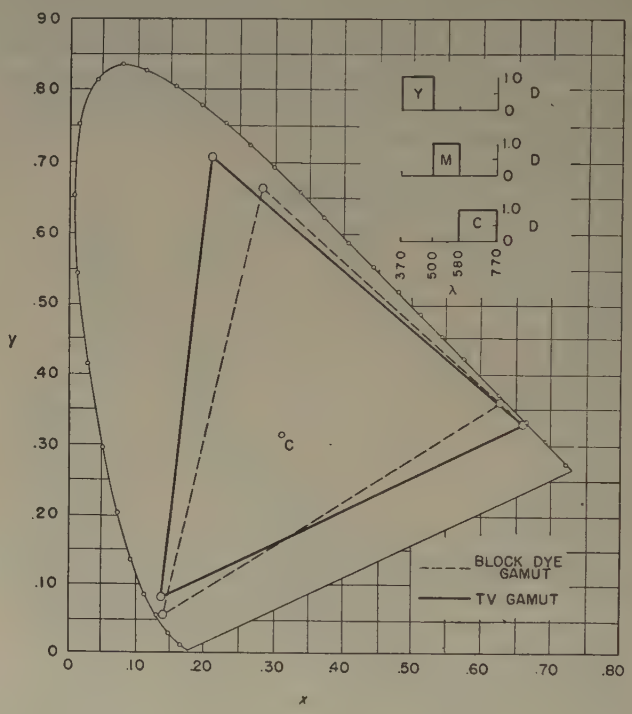

Fig. 6—Chromaticity gamuts of the color television receiver (solid lines), and a set of block dyes (broken lines). Spectral densities of unit amounts (equivalent neutral density) of the block dyes are included in the upper right-hand portion of the figure.

with a set of color television primaries and with a set of block dyes. The spectral characteristics of the block dyes chosen for this illustration are shown in the upper right-hand portion of the figure. The cyan dye controls the intensity of the transmitted red light. The magenta dye controls the intensity of the green light and the yellow the intensity of the blue light. The highest luminance white in such a system would be reproduced from a patch of film having zero concentration of each dye. A highly saturated bright red patch would have high concentrations of the yellow and magenta dyes but no cyan dye. A bright saturated green patch would have high concentrations of the yellow and cyan dyes but no magenta dye. A bright saturated blue patch would have high concentrations of the cyan and magenta dyes but no yellow dye. As the amount of light transmitted in each spectral region is controlled solely by one dye, relatively high luminance is maintained with increasing saturation of any hue. The complete chromaticity gamut and the contours of constant luminance would be quite similar to those for the color television system.

[11] R. S. O'Brien, "CBS television staging and lighting practice," *Jour. Soc. Mot. Pic. Telev. Eng.*, vol. 55, pp. 243–264; Sept., 1950.
[12] D. L. MacAdam, "The theory of the maximum visual efficiency of colored materials," *Jour. Opt. Soc. Amer.*, vol. 25, pp. 249–252; Aug., 1935.
[13] D. L. MacAdam, "Maximum visual efficiency of colored materials," *Jour. Opt. Soc. Amer.*, vol. 25, pp. 361–367; Nov., 1935.

Another set of block dyes is illustrated in Fig. 7. These dyes are also hypothetical but they agree more closely with real dyes than do those of Fig. 6. It is seen that the regions of major absorptions of each of the dyes correspond to those of Fig. 6. The cyan dye, however, has absorption in the blue and green spectral regions as well as in the red. The magenta dye has absorption in the blue and red as well as in the green, and the yellow dye has some absorption in the green as well as in the blue. Because of these overlapping absorptions these dyes are referred to as "block dyes with unwanted absorptions."

The block dyes with unwanted absorptions have the same chromaticity gamut as have the block dyes of Fig. 6. Maximum concentrations of the dyes taken in pairs yield exactly the same chromaticity points as do the maximum concentration of pairs of the other dyes. They differ basically, however, in the maximum luminance at which any chromaticity, other than neutral or white, can be obtained. This can be shown by the following considerations. A blue of low saturation can be obtained by limited amounts of cyan and magenta dyes and no yellow dye. For the dyes of Fig. 6 such a

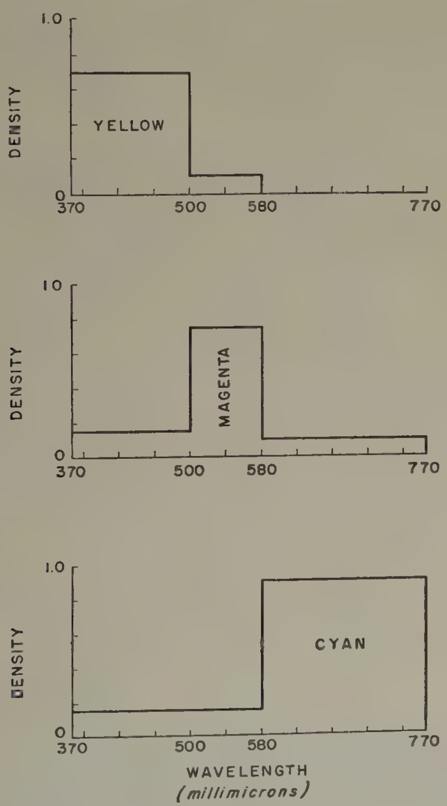

Fig. 7—Spectral density curves of unit amounts (equivalent neutral density) of a set of block dyes with unwanted absorptions.

combination would give no absorption in the blue spectral region. For the dyes of Fig. 7, because of the unwanted absorptions of the magenta and cyan dyes, there is blue absorption. Consequently, this blue must be of lower brightness than that obtainable for the dyes of Fig. 6. Increases in concentration of the magenta and cyan dyes will give an increasingly saturated series of blue colors. These colors will be darker, however, for the same chromaticity, than are those of Fig. 6. Differences for density levels of 0.5 and 1.0 are shown by the contours of constant luminance in Fig. 8. It is seen that, for a given luminance, much higher saturations can be obtained with the dyes of Fig. 6 than with those for Fig. 7. The dyes of Fig. 6 give chromaticity-luminance relationships similar to those obtainable with a color television receiver. The block dyes of Fig. 7 give much lower maximum luminances, with increasing excitation purities, than would a television receiver.

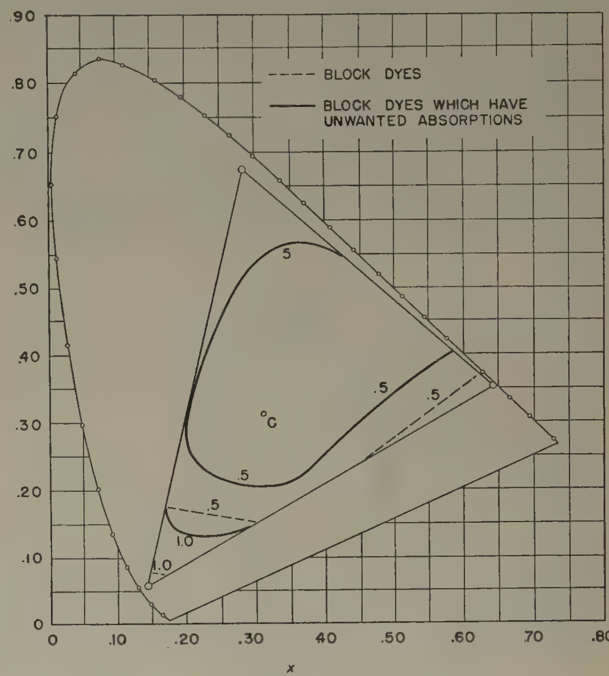

Fig. 8—Contours of maximum saturation at constant visual density of a set of block dyes with *no* unwanted absorptions (broken lines), and a set of block dyes with unwanted absorptions (solid lines).

The spectral densities of a set of real photographic dyes are illustrated in Fig. 9. These dye curves differ from those of block dyes, there being no extended vertical or horizontal sections. However, the cyan dye has absorption in the blue and green spectral regions as well as in the red, the magenta dye has absorption in the blue and red regions as well as in the green, and the yellow dye has some absorption in the green region, and a little in the red. Thus, these dyes all have unwanted absorptions. Their luminance-chromaticity relationships are not identical to those for the block dyes of Fig. 7, but they are more nearly analogous to the dyes of Fig. 7 than to those of Fig. 6.

The dyes illustrated in Fig. 9 are those of one particular color photographic process. Dyes of other photographic processes will differ in many details from those illustrated. However, the existence of unwanted absorptions, particularly for the cyan and magenta dyes, is characteristic of the dyes used in all color photographic processes. The maximum luminances (relative

to white) obtainable for saturated colors will be less for subtractive color photographic processes than for additive television receivers.

In the chromaticity diagram of Fig. 10 the "TV" locus indicates the chromaticity gamut obtainable with typical color television receiver phosphors. The "film" locus indicates the corresponding gamut of a color photographic film. This is the same film whose dyes are illustrated in Fig. 9. The film limits are based upon an assumed range of equivalent neutral density[14] of 0.0 to 3.0, a range which is more or less representative of available films.

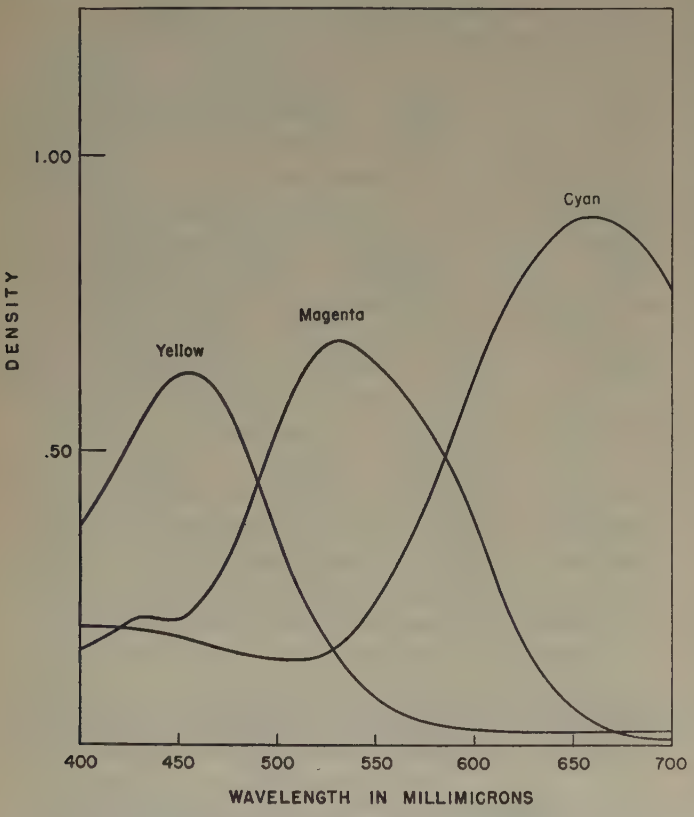

Fig. 9—Spectral density versus wavelength of unit amounts (equivalent neutral density) of a set of real photographic dyes.

Fig. 10 shows that there are no great differences between film and television as far as total chromaticity gamuts are concerned. Each system includes all of the important chromaticity areas.

Lens flare and ambient illumination desaturate the projected film image. Hence, the chromaticity range of the film record cannot be realized in projection. In color television with a tricolor picture tube, stray light within the picture tube and other system limitations cause desaturation of the kinescope image. Hence, the color television chromaticity gamut shown in Fig. 10 cannot be realized in practice. In this respect film and television have similar limitations.

[14] The term "equivalent neutral density" is defined and discussed in detail by R. M. Evans, W. T. Hanson, and W. L. Brewer, in "Principles of Color Photography," John Wiley & Sons, New York, N. Y., pp. 429–437; 1953.

The comparative colorimetric properties of color film and color television may be conveniently depicted in the following color space. Let the trichromatic coefficients, x and y, be measured along two of the three mutually-perpendicular axes, and visual density be measured along the third. Three planes in this color space are chosen for illustration. Each plane includes the neutral density axis and one of the television receiver primaries. Intersections of these planes with the x–y plane are shown by lines marked G–M, R–C, and B–Y in Fig. 10.

The colors obtainable from projected film and from the color television receiver will depend upon the luminance output ranges of the systems. For the red, green, and blue television signals, each is assumed to have a luminance range of 20, or a density range of 1.3. This is the highest density obtainable for the television system. For the color film it is assumed that the density range is 1.85. Although the basic film characteristics themselves would provide for a greater density range, lens flare in projection systems provides a practical upper limit corresponding roughly to this value. The transfer gradient does not affect the gamut of colors obtainable.

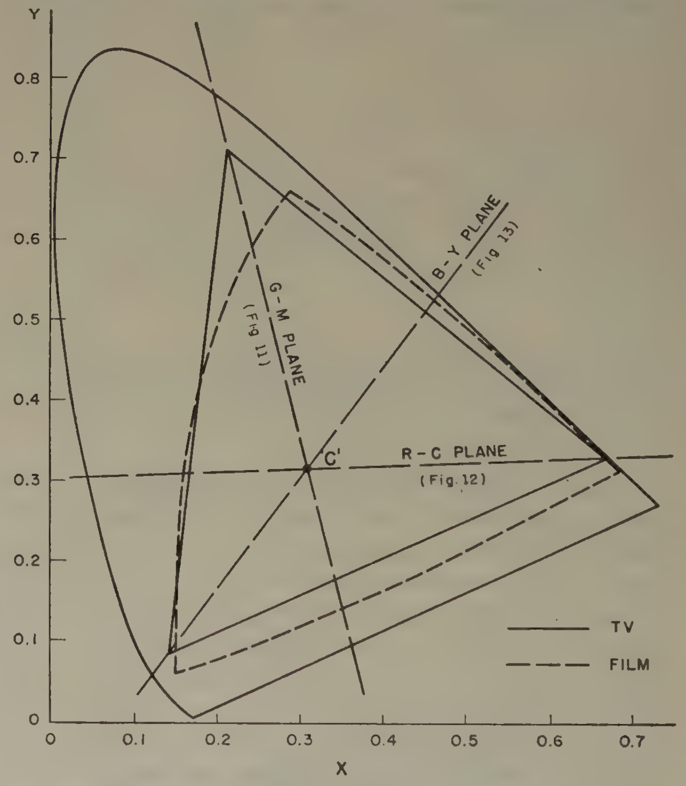

Fig. 10—Chromaticity gamuts of standard color television receiver (solid lines) and dye system in amounts (equivalent neutral densities) of 3.0 (broken lines). Dashed lines through source point "C" indicate intersections of planes normal to chromaticity diagram through the television primary points.

Fig. 11 is a representation of the limits of the color gamuts in a plane through the green primary point, through the neutral axis, and through the magenta point which is complementary to the green primary. The units along the ordinate axis of this figure are those of visual density, with zero density (maximum luminance) at the top. The abscissa axis to the right of the ordinate axis is

proportional to the distance in Fig. 10 between the illuminant point and the green primary of the television system. Increasing distance from the center line indicates increasing green saturation.

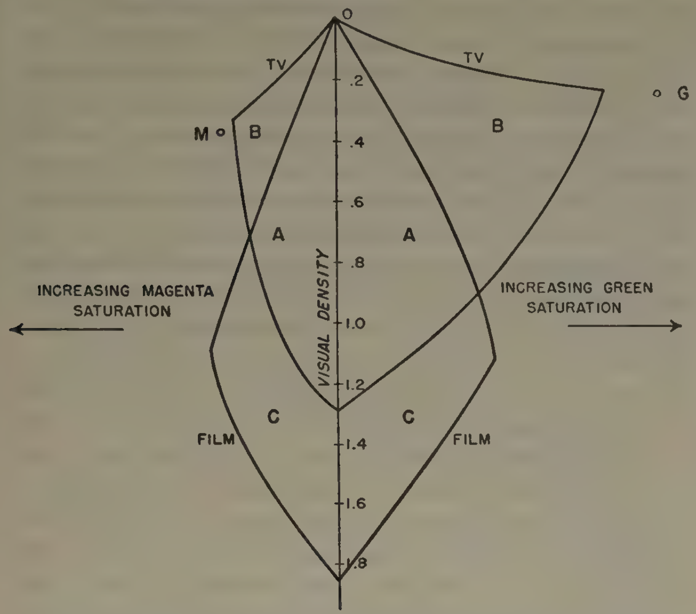

Fig. 11—Saturation versus effective visual density in the green-magenta plane. Areas A plus B represent the color gamut obtainable on a television receiver. Areas A plus C represent the gamut obtainable on film.

A white on the television receiver, in which all three phosphors are excited to their maximum amounts, is represented at the top point of the ordinate axis. Increase in green saturation at the highest possible brightness is obtained by maintaining the green phosphor at its maximum excitation, and decreasing together the excitations of the red and blue phosphors. As the red and blue phosphors contribute to the luminance, it is evident that the increase in green saturation is obtainable only at the expense of brightness. The amounts by which the visual density is increased with increasing green excitation purity is shown by the upper right portion of the "TV" locus in Fig. 11 which approaches the point "G," at the position of the green primary.

Assuming the range of excitation of each individual phospor to be 20, the maximum visual density obtainable in the picture tube in a gray or black would be 1.30. This is indicated in Fig. 11 by the intersection of the "TV" locus with the ordinate axis at 1.30. Colors of increasing green saturation at the lowest possible brightness are obtainable only by increased excitation of the green phosphor. This adds to the luminance of the color. The decrease in density with increasing saturation is shown by the lower right portion of the "TV" locus. At maximum excitation of the green phosphor this curve meets the top curve previously described.

At any given saturation, the vertical distance inside the "TV" locus indicates the available density range in the television system. This range is 1.30 along the neutral scale, decreasing to zero at the green of maximum saturation. Similarly, at any given visual density, the horizontal distance from the ordinate axis to the "TV" locus indicates the available saturation range for green hues in the television system.

The corresponding film density ranges for the series of greens of the same dominant wavelength as the television primary are inside the film locus shown in Fig. 11. The maximum luminances (minimum densities) in this case are limited by the characteristics of the dyes (Fig. 9). Because of the unwanted green absorptions of the cyan and yellow dyes, increasing the amounts of these dyes to increase saturation results in greens which are increasingly dark, and which darken at a much more rapid rate than in the television system.

The luminance range of projected film is greater than that of television. Assuming a maximum effective film density of 1.85 the bottom portion of the film locus was obtained. (The flare effect is probably of the magnitude assumed here when the entire motion picture frame is projected simultaneously. Flare may interfere less when a flying spot scanner projects the film image one point at a time.)

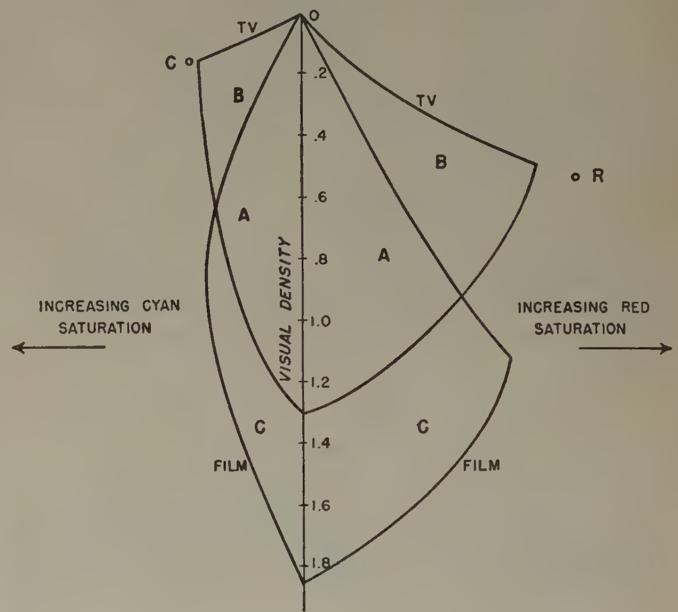

Fig. 12—Saturation versus effective visual density in the red-cyan plane. Areas A plus B represent the color gamut obtainable on a television receiver. Areas A plus C represent the gamut obtainable on film.

Fig. 11 shows that for either television or film there is a reasonably good brightness range for colors of relatively high saturation. In a television system of limited brightness range and in which exact colorimetric reproduction is set up as an ideal, however, film and television used together give a color gamut which is restricted in saturation and, for the saturations obtainable, a much limited brightness range. For any given saturation, film limits the brightness range on the high side, and the television system limits it on the low side.

The corresponding effects for the other primaries and their complementaries are illustrated in the other half of Fig. 11 and in Figs. 12 and 13. The effects of the combined television and film systems are particularly

bad for blues and greens, slightly less so for reds, and hardly present at all for yellows. Partial explanation for this is seen in Fig. 9 where the relative amounts of the unwanted absorptions of the various dyes are shown.

Color areas A and B in Figs. 11, 12, and 13 can be obtained on the color television receiver. Color areas A and C can be obtained on color film. Assuming the television system to give reasonably good colorimetric reproduction within its range, color area A can be reproduced from film onto a color television receiver with only moderate distortion. Colors in area C cannot be colorimetrically reproduced by the color television system. These colors probably would appear near the television black. Colors in area C would hardly be distinguishable from each other on the television receiver. This means that detail in the regions of high saturation, low brightness, or combinations, would be lost.

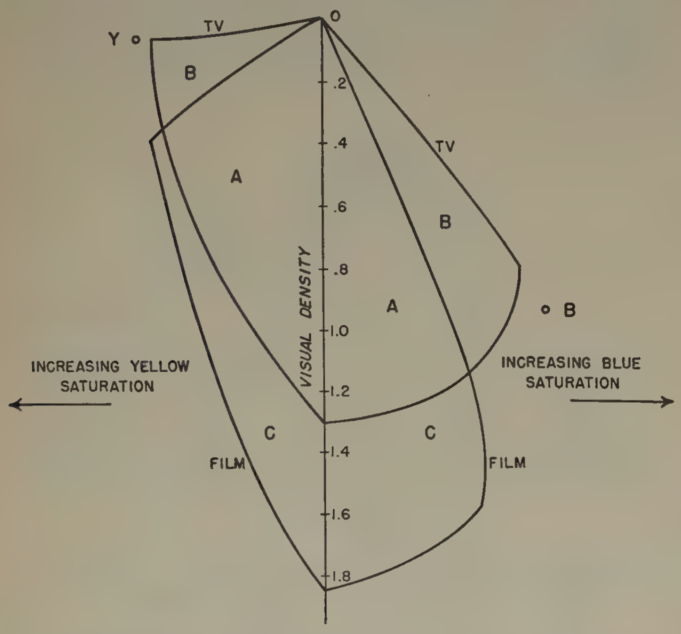

Fig. 13—Saturation versus effective visual density in the blue-yellow plane. Areas A plus B represent the color gamut obtainable on a television receiver. Areas A plus C represent the gamut obtainable on film.

Chromatic Reproduction Measurements

The theoretical data relative to color television systems illustrated in Figs. 11, 12, and 13 are based upon the nominal tristimulus values of the color television primaries and upon the assumed kinescope luminance range limitations. Attempts were made to verify the reasonableness of these assumptions by actual measurements of color television receivers. The first type of observation was made by means of 2×2-inch slides containing step wedges with increments of 0.15 density. Each density step was 3.0 mm wide and extended from top to bottom of the slide. For three different television film chains located in three different laboratories, it was found that density increments of 0.15 in the neutral scale could be distinguished up to densities of roughly 1.2. For one laboratory the value was close to 1.5 (on a trinescope) and for the others slightly less than 1.2 (on a tricolor tube). A second type of observation was made by placing Wratten filters over the neutral step wedges. In each case the range was found to be more limited with the filter combination. The reproduction decreased in saturation as the slide steps increased in density.

For the third type of observation, quantitative measurements of the kinescope outputs were made at one installation. The transfer characteristics were determined on a tricolor tube with the aid of a series of neutral density filters. For each measurement the 2×2-inch slide in the scanner consisted of a uniform neutral density filter bounded by an opaque paper mask. The area inside the bounding mask was centered in the slide and was approximately half of the total area of the slide. No room light reached the kinescope face during a measurement. The red, green, and blue light fluxes normal to the tube face were measured with a calibrated telephotometer. The telephotometer consisted of red, green, and blue isolation filters, a multiplier phototube, and associated circuitry. Luminance and chromaticity were computed from the red, green, and blue telephotometer readings. Each neutral density filter was placed in turn in the flying spot scanner. A plot of the luminance transfer characteristic is shown in Fig. 14. The curve has approximately unit slope in the highlight region. There is slight curvature throughout the length of the curve, the curvature increasing fairly rapidly for luminance values of about 1/12 to 1/15 of maximum.

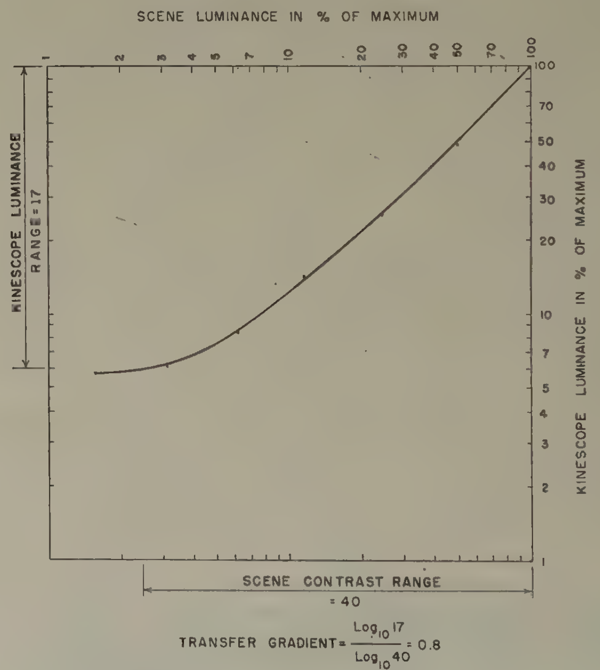

Fig. 14—Luminance transfer characteristic measured on the tricolor tube of the color television system referred to in Figs. 15 to 19.

The curve becomes nearly horizontal at about 1/17 the maximum luminance. This corresponds to a density of about 1.24. The range of reproduced luminances agrees closely with curve "B" in Fig. 4.

An analysis of the reproduced neutral scale was made from the measurements already described. The resulting

curves are shown in Fig. 15. The relative vertical displacements of the three curves have been adjusted so that they all pass through a common point at maximum luminance (the system white). If the system conformed to specifications, this white would have the chromaticity of CIE standard Source C. Even though there was some departure from this chromaticity on the monitor used, the chromaticity which was obtained established the color of the white of the system. The fact that the three curves, normalized as indicated at maximum luminance, do not remain superimposed throughout the scale indicates lack of constant color balance. Whether or not normalized at maximum luminance, the three curves must be parallel throughout the scale if constant color balance is to be maintained.

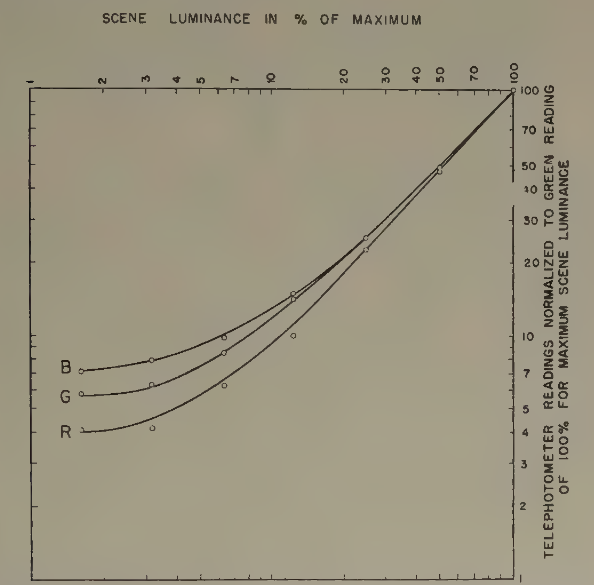

Fig. 15—Measured red, green, and blue transfer characteristics of a color television system.

Experience with color photographic processes has indicated that it is important and desirable that a series of grays be reproduced at approximately constant color balance. In regular broadcast work in color television it is likely that constant color balance reproduction of the neutral scale will be found important. To the extent possible, the red, green, and blue characteristic curves should be kept matched. For the calculations of the succeeding figures it was assumed that all three curves were superimposed on the green curve of Fig. 15. Outputs corresponding to the red and blue curves were, in effect, transposed to that of the green curve.

In a fourth type of measurement the effects, of density increases on the reproductions of colors of various chromaticities, were determined. The type three measurements were repeated with each of a number of Kodak Wratten Filters and Kodak Color Compensating (CC) Filters placed in the scanner. Chromaticity plots of the reproductions of six of the Wratten filters, a red, yellow, green, cyan, blue, and magenta, are shown in Fig. 16. The outer terminal points on the six lines represent the reproduced chromaticities of the filters. With 0.3 neutral density added to each filter, the points marked 3 were obtained, and so on for the other points shown on the plot. With each increase in density the reproduced color shows a loss in saturation even though the chromaticity of the original color remains constant. With added densities as high as approximately 1.2, the reproduction approaches the neutral point, regardless of the chromaticity of the original color.

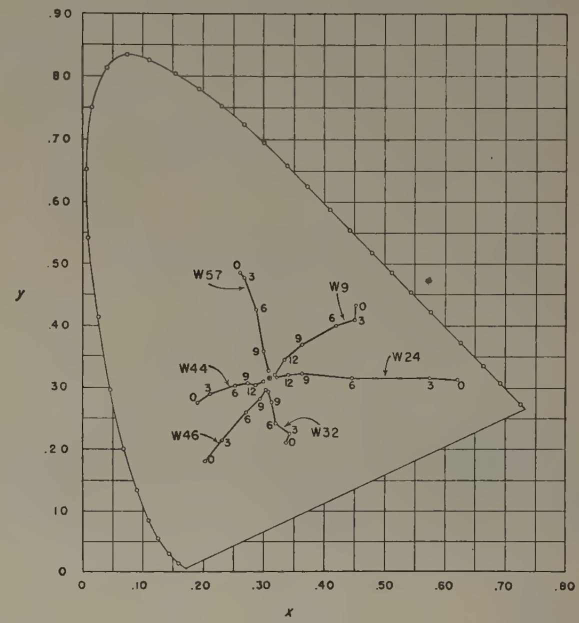

Fig. 16—Chromaticity plots of Kodak Wratten Filters in combination with a series of neutral density filters, as measured on the tricolor kinescope of a color television system. Neutral densities of 0.3, 0.6, 0.9, 1.2, and 1.5 were added.

Additional plots pertaining to the Wratten filters and to a number of the CC filters are shown in Figs. 17, 18, and 19. The theoretical television loci of Figs. 11, 12, and 13 are shown as dashed curves in these figures. The effective density of the reproduction of Wratten 57, shown in Fig. 17, is approximately 0.44. Addition of 0.3 neutral density increases the reproduced density about 0.3 and causes a slight decrease in excitation purity. Each additional increase in density increases the reproduced density and further reduces the excitation purity. Similar plots for two other green filters and two magenta filters are shown in the same figure. All the curves tend to converge to a single point on the neutral axis at a density slightly less than 1.3. Similar results for red and cyan filters are shown in Fig. 18 and for blue and yellow filters in Fig. 19. These curves show that the bottom portions of the theoretical "TV" locus agree reasonably well with those determined experimentally. No attempt was made to determine the upper locus because no filters are available which give high saturations at the high luminances necessary to sample these regions of color space. No such colors occur in natural scenes except for self-luminous objects or for scenes in which the illuminance on colored objects exceeds that on whites.

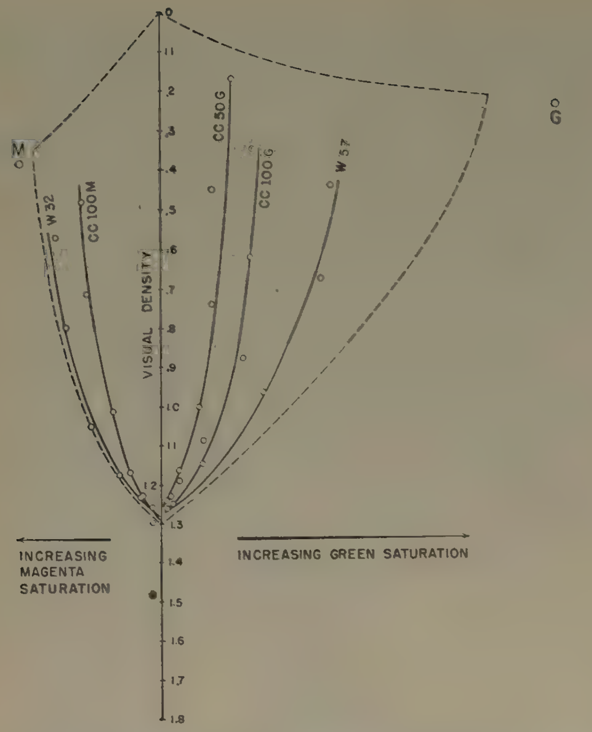

Fig. 17—Relative saturation versus visual density in the green-magenta plane for several Kodak Wratten Filters and Kodak Color Compensating Filters in combination with a series of neutral density filters. Measurements were made on the tricolor kinescope of a complete television film chain.

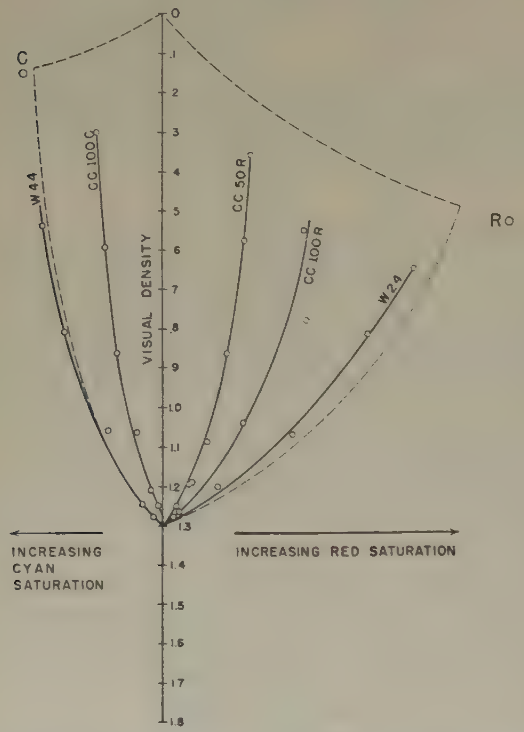

Fig. 18—Relative saturation versus visual density in the red-cyan plane for several color filters in combination with a series of neutral density filters. Measurements were made on the tricolor tube of a complete television film chain.

The data presented in these figures provide ample confirmation to the assumptions made earlier with respect to the nature of the luminance and chromatic gamut of colors obtainable in color television systems. Color films have much greater luminance ranges than can be reproduced in television. Furthermore, the attainable color gamuts of film and television do not fully overlap. If colorimetric matching of the film is approximated in the television system within the luminance output range of the latter, then the gamut of attainable colors will be greatly reduced from the gamut possible in either system by itself. Keeping in mind the nature of this relative incompatibility between color film and color television, consideration will now be given to several alternative methods for improving the appearance of televised film.

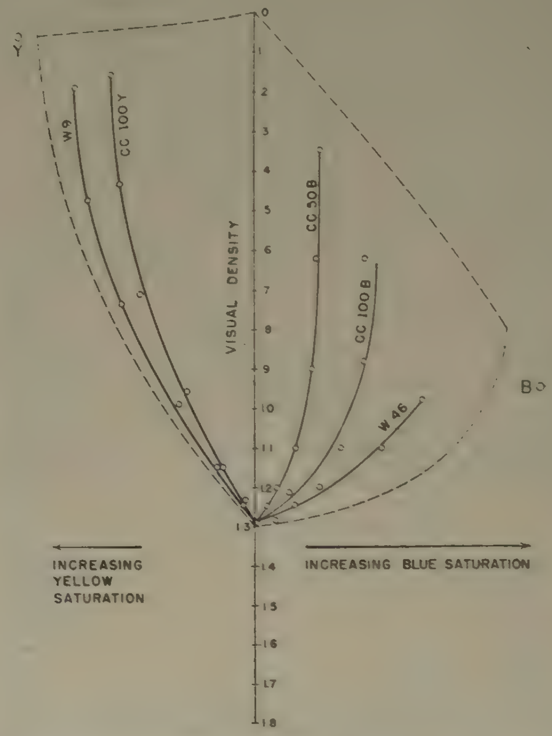

Fig. 19—Relative saturation versus visual density in the blue-yellow plane for several color filters in combination with a series of neutral density filters. Measurements were made on the tricolor tube of a complete television film chain.

Television Film Chain

The major steps in the sequence of operations involved in film utilization in color television are illustrated in Fig. 20. There is first of all an original scene to be reproduced. A record of the scene is obtained on color film. The color television signals are obtained from the color film by means of a scanner pickup unit. If the three signals correspond to X, Y, and Z at this stage and not to those which in principle will be applied to the individual red, green, and blue phosphors of the receiver, such signals are obtained by matrixing. In other systems, the red, green, and blue signals are obtained directly from the film. Once the red, green, and blue signals are obtained they are fed to a gamma operator which performs what is commonly referred to as "gamma correction." The three signal ouputs of the gamma operator must be matrixed in order to get the broadcast signal.

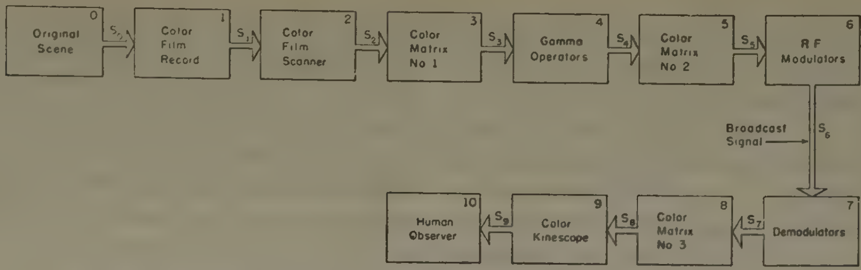

Fig. 20—Block diagram of generalized color television film chain.

At several points in the television film chain there are alternative methods for modifying the signal to make the reproduced picture more pleasing. For example, the scene itself may be modified in such a way as to give the best possible final result. The manner in which the color film images are derived from the original scenes are subject to control and modification. The first color matrix unit provides an opportunity for signal modification as do the gamma operators and the second matrix unit.

Control of Scene Luminance Range

Outdoor scenes have luminance ranges averaging about 160. Many scenes have ranges extending beyond this by a factor of 2 or more. The available density ranges in film reproductions are limited and constancy effects which are pronounced in original scenes are less pronounced in film reproductions. Therefore the film luminance output range is usually restricted. Common practice in motion picture work is to provide additional lighting for shadowed areas by means of reflectors and additional light sources. In present motion picture color photography a maximum of about 4 in the scene illumination range is recommended.

The scene luminance range can also be reduced by reducing the range of reflectances of objects to be reproduced. This is possible, for example, by excluding specular highlights and whites of high reflectance from the scene. White shirts are replaced by gray shirts and other white objects are eliminated. When reproduced on the film the light grays, being the lightest objects in the scene are seen as white.

Because television has an even lower luminance output range than has film, current recommendations for monochrome television are that the scene illumination ratio be no greater than 2.[15] This same recommendation will probably apply to color television. Improvement can be obtained if the reflectance range of objects is practically reduced through elimination of white objects in scenes to be photographed for color television. In addition to reducing the scene luminance range, this has a further advantage of increasing the apparent brightness of chromatic objects. Increasing the relative luminances of chromatic objects allows a better reproduction in terms of fitting object colors into the color television gamut. Somewhat the same effect can be obtained if the intensity of the illumination on chromatic objects is increased above that on white objects.

Control of the scene luminance range will improve the appearance of televised film. The methods above will not be helpful, however, for film which has already been exposed or for film which is exposed primarily for other purposes.

Control of Transfer Gradient

For a film with fixed scene contrast range, reduction of the effective film transfer gradient reduces the density range of the film and hence the luminance range of the televised picture. For black-and-white film this can be accomplished conveniently by reducing the development time of the film, thereby giving reduced film gamma. Somewhat the same effect can be accomplished by under-exposing either the negative or the print film because the toe portion of the film scale tends to have a slightly lower gradient than has the central region.

Transfer gradient reduction can be accomplished within the television system by rooting the signals. This is not current standard practice in monochrome television but can be employed. The pickup system must have an input range adequate for the density range of the film record.

In color television, gamma overcorrection can be accomplished within the framework of the system as it is now visualized. The gamma operators (see Fig. 20) can be set to give a greater gamma reduction than is commonly used for live pickup. However, this has two effects of consequence. First, it reduces the transfer gradient thereby reducing the luminance output range requirement, as is desired. Second, gamma overcorrection reduces color saturation. Film has gamma values exceeding unity in order to obtain colors of high saturation. A lower gamma value might improve relative brightness appearances but these improvements would be offset by reductions in color saturation. Television, with its limited luminance output range, requires a lower transfer gradient.

Matrixing of Signals

It is shown in photographic color reproduction theory[16] that the undesirable effects associated with the unwanted absorptions of the dyes can largely be eliminated through the use of photographic masking. Pho-

[15] O'Brien, loc, cit., p. 257.

[16] Evans, Hanson and Brewer, op cit., pp. 545–584.

tographic masking corresponds to matrixing of the *logarithms* of the television signals. There is no simple electronic means to accomplish this. Matrixing of the signals themselves can be accomplished easily in color television and no doubt will improve the appearance of televised film.[17] However, the primary effects would be hue and saturation changes. Linear electronic matrixing cannot reduce the luminance range for the neutral scale. It can increase brightnesses of some hues, but not all without introducing marked chromatic changes. For this reason, it appears that straight matrixing of the signals will not give the desired result.

Some studies of photographic masking theory have been based upon exact reproduction of the original scene. The basic philosophy which apparently underlies the application of photographic masking theory to color television is that the kinescope should reproduce the impression of the original scene rather than of the film record. Masking will correct for unwanted dye absorptions of color film. However, color film does not conform to simple color reproduction theory. The sensitivity distributions of color film do not correspond to color mixture curves and the color balance and scales of color reproduction depart from simple theory. Within the possibilities of the film system, however, these deviations are balanced against one another to give the most pleasing result. Hence, application of masking theory in color television may not greatly improve the reproduced impression of the original scene.

Brightness Compensation by Automatic Gain Control

One major difficulty in televising color film is the fitting together of the film and television color gamuts. The chromaticity gamuts of the two systems do not differ materially from each other. Film has a greater density range than has color television. However, the maximum brightnesses of saturated colors with respect to white are much higher on television than on film. It would therefore appear that the modifications to be sought are those which tend to reduce the effective density range of the film as reproduced on color television, and to increase the reproduced brightnesses of the saturated colors. The increases in brightnesses should depend to some extent on hue and on saturation.

The desired alterations can be accomplished through brightness compensation by automatic gain control followed by normal gamma correction. The desired alterations can be illustrated as follows: For any color with tristimulus values, X, Y, and Z, the trichromatic coefficients will be the same for X^*, Y^*, and Z^*, if $X^*=AX$, $Y^*=AY$, and $Z^*=AZ$. Such a transformation alters the luminance according to the magnitude of the muliplying factor "A." Assuming "A" to be 1.00 for the white in the system, then in accordance with the recommendations made here, it should increase in magnitude with increasing density in the neutral scale and with increasing departures from neutrality. The amount of increase should probably be greatest for blues and greens, and least for yellows and reds. Values would probably range from 1.0 to 4.0. The best choices in values must be determined empirically and probably would differ slightly for different film systems.

In order to provide suggested values for the multiplying factor, a few simple assumptions as to its mode of variation were made for assumed color photographic and television systems. The multiplying factor would be a function of the red, green, and blue signals. The multiplying factor "A" is given by: $A=1/R^{k_1}\cdot G^{k_2}\cdot B^{k_3}$. See Appendix A.

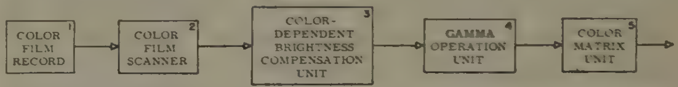

Fig. 21—Block diagram showing position of proposed color-dependent brightness compensation unit in the television film chain.

Precise values cannot at present be assigned to the parameters k_1, k_2, and k_3. It is likely that none should be greater than about 0.3. It is also likely that k_1 should be the largest, k_2 the next largest, and k_3 the smallest. It may well be that the desired results can be obtained by setting $k_3=0$, thus giving no brightness compensation as a function of the blue signal. Figs. 21 and 22 illustrate

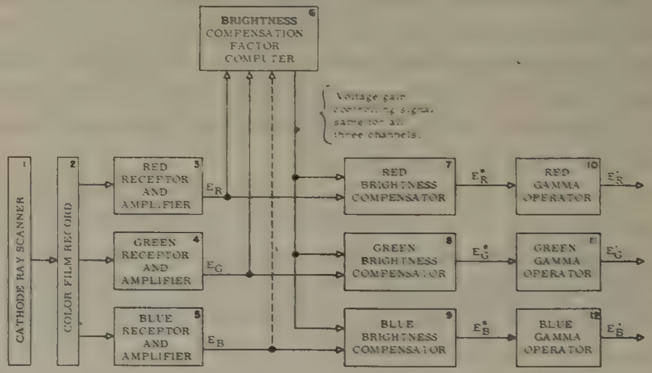

Fig. 22—Block diagram of color-dependent brightness compensation unit using automatic gain control followed by normal gamma correction.

how the proposed compensator might fit into the television film chain. Row C of Fig. 23 summarizes the mathematical operations involved in brightness compensation by automatic gain control before normal gamma correction.

For the example in Appendix A, values for the three k's are $k_1=0.18$, $k_2=0.14$, and $k_3=0.10$. These are not necessarily the most desired values but might serve as a starting point in investigating such a system.

Objections to the proposed type of brightness compensation might reasonably be raised on the grounds that displeasing effects of brightness distortions might overshadow other possible gains. However, photographic experience indicates that the brightness distor-

[17] R. P. Burr, "The use of electronic 'masking' in color television," presented at the I.R.E. Cincinnati Section Spring Technical Meeting; April 18, 1953.

		Film Scanner Output Signal	Gamma Operator Input Signal	Gamma Operator Output Signal	Color Matrix No. 2 Output Signal
	Normal Modes of Operation:	S_2	$S_3 = f(S_2)$	$S_4 = f(S_3)$	$S_5 = f(S_4)$
A	Matrix after Normal Gamma Correction	E_R E_G E_B	$S_3 = S_2$	$E_R' = (E_R)^{\frac{1}{2.2}}$ $E_G' = (E_G)^{\frac{1}{2.2}}$ $E_B' = (E_B)^{\frac{1}{2.2}}$	$E_Q' = 0.21E_R' - 0.53E_G' + 0.31E_B'$ $E_I' = 0.60E_R' - 0.28E_G' - 0.32E_B'$ $E_Y' = 0.30E_R' + 0.59E_G' + 0.11E_B'$
B	Matrix before and after Normal Gamma Correction	E_X E_Y E_Z	$E_R = 1.91E_X - 0.53E_Y - 0.29E_Z$ $E_G = -0.98E_X + 2.00E_Y - 0.03E_Z$ $E_B = 0.06E_X - 0.12E_Y + 0.90E_Z$	(Same form as above)	(Same form as above)
	Brightness Compensation Methods:	S_2	$S_3 = f(S_2)$	$S_4 = f(S_3)$	$S_5 = f(S_4)$
C	Automatic Gain Control before Normal Gamma Correction	E_R E_G E_B	$E_R^* = AE_R$ $E_G^* = AE_G$ $E_B^* = AE_B$ (See Figures 21 and 22)	$E_R' = (E_R^*)^{\frac{1}{2.2}}$ $E_G' = (E_G^*)^{\frac{1}{2.2}}$ $E_B' = (E_B^*)^{\frac{1}{2.2}}$	$E_Q' = 0.21E_R' - 0.53E_G' + 0.31E_B'$ $E_I' = 0.60E_R' - 0.28E_G' - 0.32E_B'$ $E_Y' = 0.30E_R' + 0.59E_G' + 0.11E_B'$
D	Gamma Over-correction Followed by Modified Matrix	E_R E_G E_B	$S_3 = S_2$	$E_R'' = (E_R)^{\frac{1}{\gamma}}$ $E_G'' = (E_G)^{\frac{1}{\gamma}}$ $E_B'' = (E_B)^{\frac{1}{\gamma}}$	$E_Q' = a_{11} E_R'' + a_{12} E_G'' + a_{13} E_B''$ $E_I' = a_{21} E_R'' + a_{22} E_G'' + a_{23} E_B''$ $E_Y' = a_{31} E_R'' + a_{32} E_G'' + a_{33} E_B''$
E	Modified Matrix Followed by Gamma Over-correction	E_R (or E_X) E_G (or E_Y) E_B (or E_Z)	$E_R^o = a_{11}E_R + a_{12}E_G + a_{13}E_B$ $E_G^o = a_{21}E_R + a_{22}E_G + a_{23}E_B$ $E_B^o = a_{31}E_R + a_{32}E_G + a_{33}E_B$	$E_R' = (E_R^o)^{\frac{1}{\gamma}}$ $E_G' = (E_G^o)^{\frac{1}{\gamma}}$ $E_B' = (E_B^o)^{\frac{1}{\gamma}}$	$E_Q' = 0.21E_R' - 0.53E_G' + 0.31E_B'$ $E_I' = 0.60E_R' - 0.28E_G' - 0.32E_B'$ $E_Y' = 0.30E_R' + 0.59E_G' + 0.11E_B'$

Fig. 23—Summary of equation forms relating to signals in the television film chains discussed.

tions would not be unduly displeasing. Several Kodachrome slides were masked to simulate the brightness compensation proposed here. Viewed on a trinescope and on a monochrome monitor, improved results were observed in preliminary tests.

Color photographic processes are intentionally designed with average gamma values in the middle tone scales considerably greater than unity. High gamma values expand the brightness scale and, no doubt, color photographs would be even more pleasing in their brightness characteristics if lower gamma values could be employed. Because of the nature of the dyes available for color photography, however, lower gamma values result in reproduction colors of lower saturation. The gamma values actually employed have been arrived at empirically in such a way as to obtain reasonably high saturations without overly expanding the brightness scale. Brightness compensation of the type suggested here would compensate for the expanded brightness scale introduced by the color photographic process and, probably, go somewhat in the opposite direction.

Brightness compensation may be considered from a slightly different point of view as a means of fitting the film color gamut to the television color gamut. On this basis it is analogous to the problem in black-and-white photography of making a print from a negative. This problem has been studied extensively by Jones and Nelson.[18,19] One of their findings was that for first-choice prints the contrast of the printing paper should be chosen so that its log-exposure range is nearly equal to the density range of the negative.

The implication of this finding is that the full density range of the print material should be utilized in exposing from a negative, almost independently of the original scene brightness range. A low contrast scene, giving a small density range in the negative, should be printed onto a high contrast paper. A high contrast scene, giving

[18] L. A. Jones and C. N. Nelson, "The control of photographic printing by measured characteristics of the negative," *Jour. Opt. Soc. Amer.*, vol. 32, pp. 558–619; Oct., 1942.

[19] L. A. Jones and C. N. Nelson, "Control of photographic printing; improvement in terminology and further analysis of the results," *Jour. Opt. Soc. Amer.*, vol. 38, pp. 897–920; Nov., 1948.

a large density range in the negative, should be printed onto a low contrast paper. Within limits, the reproduced brightness scale may be expanded or compressed with pleasing results. Utilization of the full range of densities in the print material is more important than faithful brightness scale reproduction.

Multiple contrast grades of print material are not available for most color photographic processes so that the corresponding types of scale adjustments are not feasible. Engineers working on printing problems, however, consider it axiomatic that the most desirable contrast relationship between original and print is one in which the full density range of the print material is utilized.

Alternative Methods of Brightness Compensation

The type of brightness compensation described in the preceding section may be approximated in alternative ways. See Fig. 23. Gamma overcorrection accomplishes part of the desired result by reducing the required luminance output range. Losses in saturations accompany this change, however. Matrixing of the red, green, and blue signals will not materially improve the brightness reproduction, but can be employed to increase saturations. Thus, a combination of gamma over-correction and matrixing of the signals may accomplish the desired result.

Matrixing of the signals may come before or after gamma correction. A set of equations is developed in Appendix B, based upon gamma over-correction followed by a modified matrix. Normal gamma correction involves an exponent 1/2.2 or 0.46. For gamma over-correction this figure was reduced by a factor of 0.57, giving an exponent of $(0.57)(0.46)=0.26$.

To arrive at suitable modified matrix equations it was assumed that the desired end result was that given by the brightness compensation developed in Appendix A. For a few selected colors, the input signals and the required output signals to the kinescope were calculated. The conversion equations were then found by the method of least squares. Taking E_R'', E_G'', and E_B'' to represent the gamma over—corrected signals, and E_R', E_G', and E_B' as those to be applied to the kinescope grids, the resulting equations were:

$$\begin{aligned} E_R' &= 1.43E_R'' - 0.25E_G'' - 0.18E_B'' \\ E_G' &= -0.31E_R'' + 1.48E_G'' - 0.17E_B'' \\ E_B' &= -0.32E_R'' - 0.26E_G'' + 1.58E_B''. \end{aligned} \tag{1}$$

In actual practice, direct use of these matrixing equations is not required. The signals E_Q', E_I', and E_Y' are normally obtained from E_R', E_G', and E_B' by the equations:

$$\begin{aligned} E_Q' &= 0.21E_R' - 0.53E_G' + 0.31E_B' \\ E_I' &= 0.60E_R' - 0.28E_G' - 0.32E_B' \\ E_Y' &= 0.30E_R' + 0.59E_G' + 0.11E_B' \end{aligned} \tag{2}$$

or in terms of color difference signals:

$$\begin{aligned} E_Q' &= 0.48(E_R' - E_Y') + 0.41(E_B' - E_Y') \\ E_I' &= 0.74(E_R' - E_Y') - 0.27(E_B' - E_Y') \\ E_Y' &= 0.30E_R' + 0.59E_G' + 0.11E_B'. \end{aligned} \tag{3}$$

Combination of sets (1) and (2) yields E_Q', E_I' and E_Y' directly from the gamma over-corrected signals:

$$\begin{aligned} E_Q' &= 0.36E_R'' - 0.90E_G'' + 0.54E_B'' \\ E_I' &= 1.05E_R'' - 0.48E_G'' - 0.57E_B'' \\ E_Y' &= 0.21E_R'' + 0.77E_G'' + 0.02E_B'' \end{aligned} \tag{4}$$

or in terms of color difference signals:

$$\begin{aligned} E_Q' &= 0.63(E_R'' - E_Y') + 0.57(E_B'' - E_Y') \\ E_I' &= 1.18(E_R'' - E_Y') - 0.55(E_B'' - E_Y') \\ E_Y' &= 0.21E_R'' + 0.77E_G'' + 0.02E_B''. \end{aligned} \tag{5}$$

No additional steps are required in the sequence of operations. Row D of Fig. 23 summarizes the operations involved in brightness compensation by gamma over-correction followed by a modified matrix.

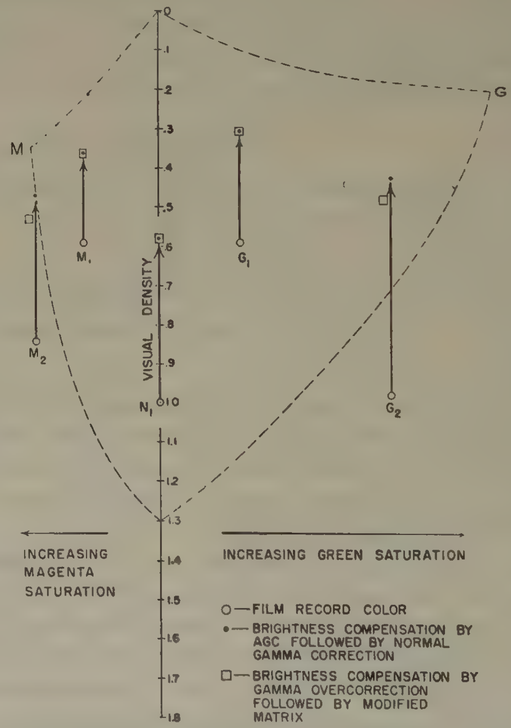

Fig. 24—Computed results for two forms of brightness compensation for film record colors in the green Magenta plane.

The reproduction characteristics obtained by means of the brightness compensation methods described are illustrated in Figs. 24, 25, and 26. The visual densities and relative excitation purities of the film colors, in their hue planes, are shown by the small circles. Brightness compensation by automatic gain control yields reproductions shown by the small solid dots. Excitation

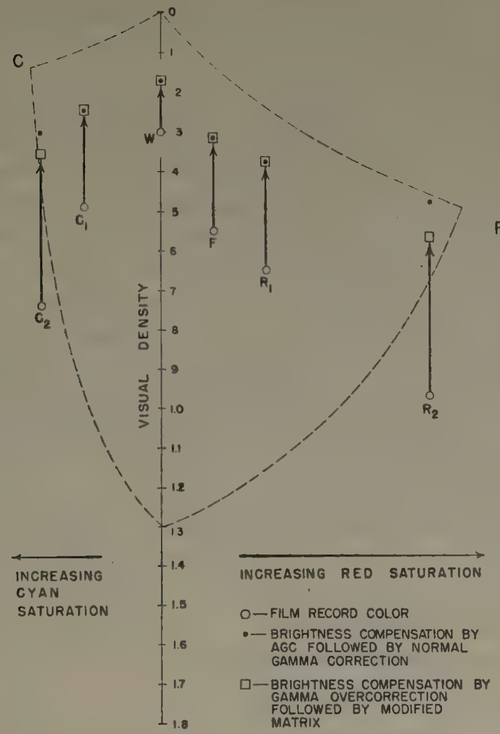

Fig. 25—Computed results for two forms of brightness compensation for film record colors in the red-cyan plane.

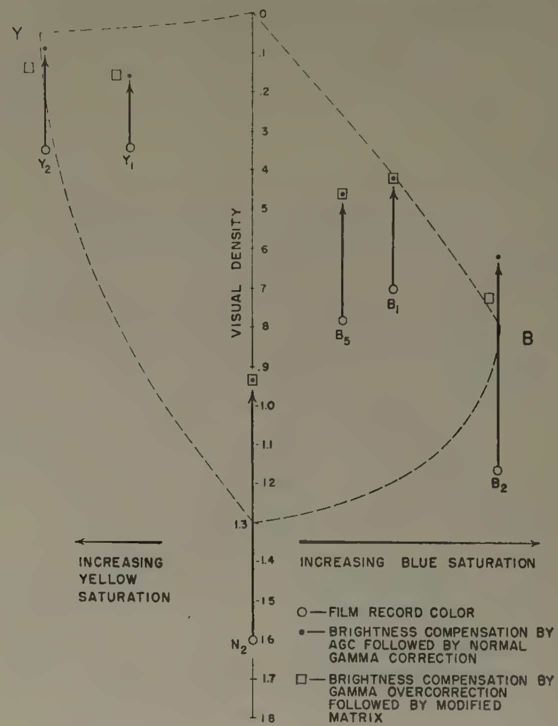

Fig. 26—Computed results for two forms of brightness compensation for film record colors in the blue-yellow plane.

purities remain constant and density decreases according to the hue, saturation, and lightness of the original color. Brightness compensation by gamma overcorrection followed by a modified matrix, gives similar results as shown by the small open squares.

Calculations were also made to examine the possibility of a modified matrix followed by gamma overcorrection and with normal subsequent treatment of the signal. See Row E of Fig. 23 for a summary of the operations involved. Reasonably good approximation to direct brightness compensation was obtained for colors of low saturation. Colors of high saturation gave less satisfactory results.

Conclusion

Color television is limited in luminance output range, and can reproduce saturated colors only at relatively high luminance. Color film has a much greater luminance output range, but reproduces saturated colors only at lower luminances. Thus the color gamuts of film and television do not fully overlap.

Assumptions as to the luminance and chromatic characteristics of color television have been supported by experimental measurements. Within the present limitation of color television, the authors believe that the appearance of televised film will be improved if the film colors of low luminance and those of high saturation can be raised in luminance by "brightness compensation." The theory of brightness compensation is developed and two methods are proposed for inserting brightness compensation into the television film chain.

Appendix A

Brightness Compensation by Automatic Gain Control

1. General Development

Let R, G, and B denote the magnitudes of the red, green, and blue signal voltages from the color film scanner. (R, G, and B are used here rather than E_R, E_G, and E_B in order to simplify the notation in the equations to follow.) Let R^*, G^*, and B^* denote the corresponding signal voltages after color-dependent brightness compensation. These two sets of signals are each so normalized for the highest intensity white in the film record,

$$R = G = B = 1.00 \quad \text{and}$$
$$R^* = G^* = B^* = 1.00. \tag{6}$$

Let A denote the brightness compensation factor by which R, G, and B are multiplied to obtain R^*, G^*, and B^* respectively.

$$R^* = AR, \quad G^* = AG \quad \text{and}$$
$$B^* = AB, \text{ where } A \geqq 1.00. \tag{7}$$

The factor A is not constant. Its magnitude depends upon the position in color-space of each film image point being scanned. This factor introduces no hue shift. It does change the brightness of points in color-space.

Let N denote the "neutral" component of the signal before brightness compensation. It equals the largest of the three signals R, G, or B. Let N^* denote the "neutral" component of the signal after brightness compensation. It equals the largest of the three signals R^*, G^*, or B^*.

The set of signal voltages R, G, and B (or set R^*, G^*, and B^*) may, in principle, be used in a linear receiver to reproduce the image from the film record. Define the effective densities of the reproduced images by the following equations:

$$D_r = -\log_{10} R \quad D_r^* = -\log_{10} R^* \quad D_n = -\log_{10} N$$
$$D_g = -\log_{10} G \quad D_g^* = -\log_{10} G^* \quad D_n^* = -\log_{10} N^* \quad (8)$$
$$D_b = -\log_{10} B \quad D_b^* = -\log_{10} B^*.$$

Let the value of A be determined by the equation

$$\log_{10} A = k_0 D_n + k_1(D_r - D_n) + k_2(D_g - D_n) + k_3(D_b - D_n) \quad (9)$$

where k_0, k_1, k_2, and k_3 are empirically determined constants of the brightness compensating system. From examination of (9) the following is evident:

For neutrals A is determined entirely by k_0. For the primary colors and their complementaries at maximum brightnesses the values of A are determined chiefly as follows: cyans by k_1, magentas by k_2, yellows by k_3, reds by k_2 and k_3, greens by k_1 and k_3, and blues by k_1 and k_2.

Equation (9) may be rearranged as follows:

$$\log_{10} A = (k_0 - k_1 - k_2 - k_3)D_n + k_1 D_r + k_2 D_g + k_3 D_b, \quad \text{or} \quad (10)$$

$$A = \frac{N^{(k_1+k_2+k_3-k_0)}}{R^{k_1} G^{k_2} B^{k_3}}. \quad (11)$$

Equation (9), or (10), or (11), may be used to establish the brightness compensation factor A in a real system.

2. Applications

From (9) it follows that for any neutral, $\log_{10} A = k_0 D_n$. As $N^* = AN$ for any color, then for a neutral:

$$D_n^* = D_n - \log_{10} A, \qquad D_n^* = D_n - k_0 D_n,$$
$$k_0 = \left(1 - \frac{D_n^*}{D_n}\right). \quad (12)$$

For the film and television systems assumed in Figs. 11 to 13, $D_n = 1.85$, $D_n^* = 1.30$. For these values of D_n and D_n^*, $k_0 = 0.3$. For a flying spot scanner, D_n may exceed 1.85, perhaps being as high as 2.60. For an assumed maximum of 2.60, $k_0 = 0.5$. The value of k_0 should probably lie within the range of 0.3 to 0.5 for complete compensation of neutrals of low brightness.

To determine values of k_1, k_2, and k_3, colors other than neutrals must be considered. One means of doing this is to consider a red, a green, and a blue, each of medium saturation at the highest brightness possible in the film system. It is then assumed that the brightnesses of these colors are to be raised by the television system to the highest brightnesses which can be reproduced on the receiver. In one example in which this was done k_0 was assumed to have a value of 0.4, and values of $k_1 = 0.25$, $k_2 = 0.21$, $k_3 = 0.17$ were obtained. Monochromatic pick-ups at the wavelengths 620 mμ, 540 mμ, and 450 mμ were assumed. Other numerical examples in which other colors and other wavelengths were used gave different values for k_1, k_2, and k_3, but they were of the same general orders of magnitude.

To simplify the equipment necessary for introducing brightness compensation it would be desirable that the exponent of N in (11) be equal to zero. This means that $k_0 = k_1 + k_2 + k_3$. For the example above, the sum of k_1, k_2, and k_3 is considerably greater than k_0. Complete compensation for the brightness losses associated with increasing saturation was also assumed. More pleasing results might be obtained if less compensation were introduced. For example, each of the above values of k_1, k_2, and k_3 might be reduced by 0.07 giving $k_1 = 0.18$, $k_2 = 0.14$, and $k_3 = 0.10$. Reasonable compensation would then be made and the sum of the values of k_1, k_2, and k_3 would be approximately equal to k_0.

This discussion indicates approaches which may be made to the problem of assigning values to k_0, k_1, k_2, and k_3. The particular numerical values are probably correct in terms of general order of magnitude, but no more than this is claimed for them.

Appendix B

Brightness Compensation by Gamma Over-Correction Followed by Modified Matrix

1. General Development

Let R, G, and B denote the magnitudes of the red, green, and blue signal voltages from the color film scanner. (R, G, and B are used here rather than E_R, E_G, and E_B in order to simplify the notation in the equations to follow.) These are normalized so that for the white of the film record:

$$R = G = B = 1.00. \quad (13)$$

Let R'', G'', and B'' denote the magnitudes of the signal voltages following gamma overcorrection, or:

$$R'' = R^{1/\gamma} \qquad G'' = G^{1/\gamma} \qquad B'' = B^{1/\gamma}. \quad (14)$$

The value of γ equals the normal gamma correction 2.2, divided by the amount of overcorrection desired. Thus, if the overcorrection factor is chosen to be 0.57, $\gamma = 2.2/0.57 = 3.9$ and $1/\gamma = 0.26$.

Let R^*, G^*, and B^* denote the effective brightness compensated signals exciting the phosphors of the kinescope. As described in Appendix A,

$$R^* = AR \quad G^* = AG \quad B^* = AB \quad A \geqq 1.00. \quad (15)$$

Let R', G', and B' denote the gamma corrected signal voltages as they are to be applied to the grids of the kinescope, or:

$$R' = (R^*)^{1/(2.2)} \quad G' = (G\ )^{1/(2.2)} \quad B' = (B^*)^{1/(2.2)}. \quad (16)$$

Select three, or preferably more, color films areas which sample the color gamut to be televised. Determine R, G, and B for each area. This determination may be made by calculations from spectrophotometric curves of the areas, or more directly from densitometer measurements, provided that suitable filters are employed.

Calculate for each color the values of R'', G'', and B'', using (14). Apply (15) and (16) to determine R', G', and B'. The value of A is determined for each color in accordance with the procedures described in Appendix A. Assume the relationships between R', G', and B' and R'', G'', and B'' to be of the form:

$$\begin{aligned} R' &= a_{11}R'' + a_{12}G'' + a_{13}B'' \\ G' &= a_{21}R'' + a_{22}G'' + a_{23}B'' \\ B' &= a_{31}R'' + a_{32}G'' + a_{33}B''. \end{aligned} \tag{17}$$

If three color areas have been used, substitution of the three values of R' and the three values of R'', G'', and B'' gives three equations in a_{11}, a_{12}, and a_{13}. From these three equations, assuming them to be independent, a_{11}, a_{12}, and a_{13} can be determined. If more than three color areas have been used, a least squares solution is employed to determine values of a_{11}, a_{12}, and a_{13}. Similarly, using the same data for R'', G'', and B'', and the data for G', and B', values of a_{21}, a_{22}, and a_{23}; a_{31}, a_{32}, and a_{33} can be determined.

To maintain proper normalization, conditional equations should be applied so that $a_{11}+a_{12}+a_{13}=1.00$, $a_{21}+a_{22}+a_{23}=1.00$, and $a_{31}+a_{32}+a_{33}=1.00$. The equations in matrix form, for the best least squares solution, become the following:

$$\begin{Bmatrix} \sum R_i'^2 & \sum R_i'G_i' & \sum R_i'B_i' & 1 \\ \sum R_i'G_i' & \sum G_i'^2 & \sum G_i'B_i' & 1 \\ \sum R_i'B_i' & \sum G_i'B_i' & \sum B_i'^2 & 1 \\ 1 & 1 & 1 & 0 \end{Bmatrix} \begin{Bmatrix} a_{11} & a_{21} & a_{31} \\ a_{12} & a_{22} & a_{32} \\ a_{13} & a_{23} & a_{33} \\ \lambda_1 & \lambda_2 & \lambda_3 \end{Bmatrix}$$

$$= \begin{Bmatrix} \sum R_i''R_i' & \sum G_i''R_i' & \sum B_i''R_i' \\ \sum R_i''G_i' & \sum G_i''G_i' & \sum B_i''G_i' \\ \sum R_i''B_i' & \sum G_i''B_i' & \sum B_i''B_i' \\ 1 & 1 & 1 \end{Bmatrix}. \tag{18}$$

The Lagrangian multipliers λ_1, λ_2, and λ_3, are introduced for the conditional equations, but their values need not be determined.

For normal signal transmissions, E_I', E_Q', and E_Y' are given in the form:

$$\begin{aligned} E_I' &= b_{11}R' + b_{12}G' + b_{13}B' \\ E_Q' &= b_{21}R' + b_{22}G' + b_{23}B' \\ E_Y' &= b_{31}R' + b_{32}G' + b_{33}B'. \end{aligned} \tag{19}$$

Substitution of the quantities equal to R', G', and B', of (17) into (19) gives E_I', E_Q', and E_Y' directly in terms of R'', G'', and B'', the gamma over-corrected signals.

2. Application

To derive sets (20) and (1), 10 areas of color film were used. Six of these represented red, green, blue, cyan, magenta, and yellow patches of relatively low density and reasonably high saturation. The signal values for the red color, for example, were $R=0.398$, $G=0.159$, and $B=0.159$. These patches are identified as R_1, G_1, B_1, C_1, M_1, and Y_1 in Figs. 24, 25, and 26. Four additional colors were chosen to represent colors frequently photographed. These included a near white ($R=G=B=0.501$), a neutral gray ($R=G=B=0.100$), flesh ($R=0.363$, $G=0.251$, $B=0.219$), and blue sky ($R=0.123$, $G=0.162$, $B=0.282$). These colors are identified as W, N_1, F, and B_5 in Figs. 24, 25, and 26. Values of R', G', B', R'', G'', and B'' were determined as explained above. Solutions of equations corresponding to (18) gave values for the a's. Applying these values, R', G', and B' were given in terms of R'', G'', and B'' as:

$$\begin{aligned} R' &= 1.43R'' - 0.25G'' - 0.18B'' \\ G' &= -0.31R'' + 1.48G'' - 0.17B'' \\ B' &= -0.32R'' - 0.26G'' + 1.58B''. \end{aligned} \tag{20}$$

Equations for E_Q', E_I', and E_Y' are given in the body of the paper.

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The Use of Electronic Masking in Color Television*

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Summary—The nature of the "reproducing primaries" employed by most subtractive color processes is such that undesirable cross-coupling exists between the various color separation images originally recorded by the taking sensitivities of the film. When using subtractive color transparencies as original material for color television transmissions, the output signals from the pickup device may be thought of as integral density measurements of the film. If the characteristics of the film are known, it is possible to devise an electrical network which will partially remove the photographic crosscoupling. For some types of subtractive transparencies color television reproduction is subjectively enhanced by this procedure.

Introduction

Photographic color transparencies employing subtractive dye systems as color reproducers are almost certain to play a large part in providing original program material for any commercial color television service. Subject matter of this type currently enjoys an advantage over "live talent" for television use in that it may be electronically scanned by apparatus which is inherently free from registration difficulties and which is capable of a high degree of excellence in technical performance.

When a color transparency is reproduced by means of a color television system the conventional slide projector or viewing device is replaced by a set of electronic apparatus which terminates in a color television display. It is well known that the television link may be theoretically arranged as a colorimetrically exact system;[1] the reproduced image will therefore be identical in appearance with the directly viewed original transparency. Under these conditions, the transparency operates as a "connection" between the observer and the original scene,—or, more exactly, between the television system and the scene.

The purpose of this paper is to discuss the television system and the photographic process as an integrated whole; that is, as a complete color reproducing system. We shall show that the performance capabilities of such a complete color reproducing system are largely controlled by the degradations inherent within the photographic process, and that the television system may be theoretically adjusted so as to partially offset these degradations.

Photography and Television—A Complete Color System

Fig. 1 provides a simplified diagram of a "Complete Color System" involving both a photographic and a television link. The performance of each of the two major elements in this system will be examined with a view towards optimizing the performance of the whole as an integrated unit.

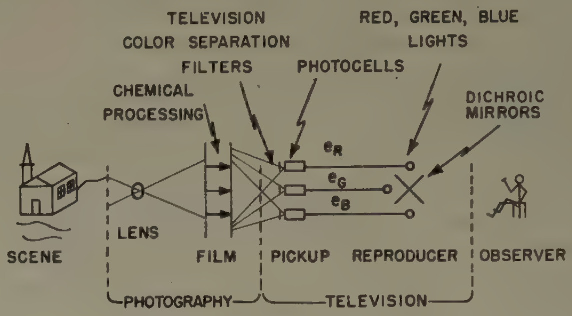


Fig. 1

At the left of the diagram is shown a schematic representation of the original scene which is brought to a focus upon the sensitive photographic emulsions by the camera lens. The information perceived by the receptors of the film is stored as a latent image until it is converted, by chemical processing, into a dye transparency. The transparency is then analyzed by the television pickup apparatus, so that electrical signals describing the transparency are transmitted to the remote color television display.

The final connection between the observer and the rest of the system is established by the reproducing primaries of the color television display. As is well known, such a display is capable of reproducing all chromaticities lying within the gamut defined by the chosen reproducing primaries, as shown in Fig. 2. We shall assume that the television components of Fig. 1 operate as a linear system, so that colorimetric fidelity may theoretically be attained within the television process.

The Television Process

The symbols e_R, e_G, and e_B in Fig. 1 are normalized quantities. They represent the electrical "tristimulus value" signals which control the reproducing primaries and may be defined by the expressions:[2]

$$\begin{aligned} e_R &= k_R \int_{400}^{700} H(\lambda) T_R(\lambda) d\lambda \\ e_G &= k_G \int_{400}^{700} H(\lambda) T_G(\lambda) d\lambda \qquad (1) \\ e_B &= k_B \int_{400}^{700} H(\lambda) T_B(\lambda) d\lambda \end{aligned}$$

where

* Decimal classification: R583×770.2836. Original manuscript received by the Institute, July 23, 1953.

† Hazeltine Corporation, Little Neck, N. Y.

[1] F. J. Bingley, "Colorimetry in color television," Parts I and II, pp. 48–57, this issue.

[2] W. T. Wintringham, "Color television and colorimetry," Proc. I.R.E., vol. 39, pp. 1135–1172; October, 1951.

$H(\lambda)$ is spectral characteristic of any radiance presented to the photocells and associated filters,

$T_R(\lambda)$, $T_G(\lambda)$, $T_B(\lambda)$ are the spectral sensitivities of the photocell-and-filter combinations, and

k_R, k_G, k_B are suitably chosen electro-optical conversion coefficients (gains).

We may arrange the display so that when $e_R = e_G = e_B = 1.0$ the emergent light has a chromaticity corresponding to $x = 0.33$, $y = 0.33$ and a luminous intensity of 100.0 foot lamberts. The contribution of each of the primaries to this luminous intensity may be shown to be approximately 60 foot lamberts from green, 30 foot lamberts from red, and 10 foot lamberts from blue. For the sake of convenience this set of display adjustments will be assumed in calculating and plotting the data shown later in this paper.

The operation of the television process has therefore been defined so that it is completely straightforward. It should be noted that the only significant variables at our disposal are the taking sensitivities $T_R(\lambda)$, $T_G(\lambda)$, and $T_B(\lambda)$. By allowing the possibility of negative "lobes" in these sensitivities we may achieve perfect colorimetric fidelity within the television system, so that any color, i.e., C in Fig. 2, will be exactly reproduced.[3]

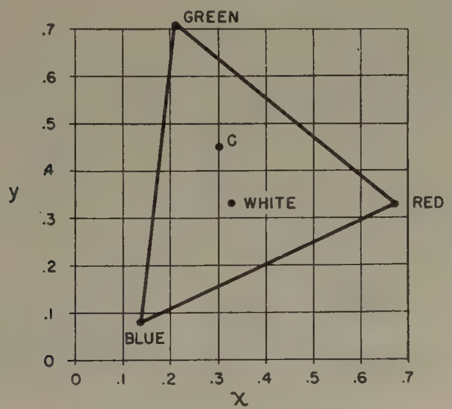


Fig. 2

The Photographic Process

The operation of the photographic process[4] is not as simple as that of the television components. To begin with, information describing the original scene is stored within the film in the form of a set of latent images, as we have previously mentioned. In the case of a reversal[4] type color process such as Kodachrome or Ektachrome, for example, these latent images are first reduced to silver deposits by the action of a developer, as shown in Fig. 3. The material then receives a "reversal exposure" which activates all those portions of the emulsion layers which were not originally affected by the initial exposure. The film is next immersed in a series of one or more color developers so that the reversal exposure is also reduced to a set of silver images. During this treatment the oxidation products of the silver development react with the color developer and a color "coupler"[5] so as to form a set of dye images within the film. The concentrations of these dyes at any point are primarily determined by the amount of silver which has been reduced in the immediate vicinity. Consequently, at the completion of color development, the film contains an "original" set of silver images, a "reversal" set of silver images, and a "reversal" set of dye images. Both sets of silver images are then removed by the action of the chemical bleach which constitutes the final step in the process. The end result is therefore a transparent dye image.

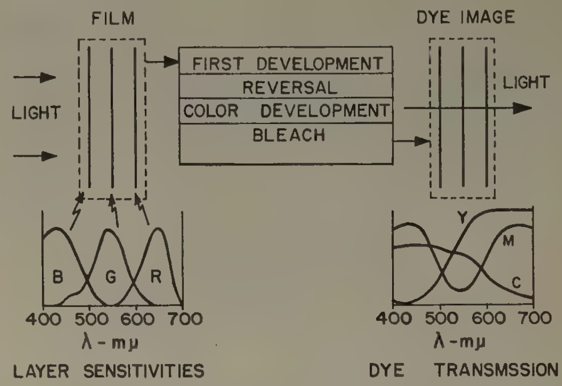


Fig. 3

As a first step in a more detailed study of the photographic system we may construct a block diagram as in Fig. 4. For this illustration, the input elements to the chemical processing have been replaced by a group of three photocells and optical filters having effective taking sensitivities which are identical with those of the film. One may then define a set of quantities which may be thought of either as "voltages" or as "integrated exposures." That is:

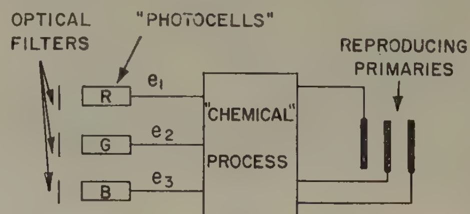


Fig. 4

$$
\begin{aligned}
e_1 &= k_1 \int_{400}^{700} S_R(\lambda) R(\lambda) I(\lambda) d\lambda \\
e_2 &= k_2 \int_{400}^{700} S_G(\lambda) R(\lambda) I(\lambda) d\lambda \qquad (2) \\
e_3 &= k_3 \int_{400}^{700} S_B(\lambda) R(\lambda) I(\lambda) d\lambda
\end{aligned}
$$

[3] A. C. Hardy and F. L. Wurzburg, Jr., "The theory of three color reproduction," *Jour. Opt. Soc. Amer.*, vol. 27, pp. 227–240; July, 1937.

[4] C. B. Neblette, "Photography: Its Materials and Processes," 5th ed., D. Van Nostrand Co., New York, N. Y., pp. 449–466; 1952.

[5] *Ibid.*, pp. 218–223.

where

$S_R(\lambda)$, $S_G(\lambda)$, $S_B(\lambda)$ are the taking sensitivities of the film,

$R(\lambda)$ is the spectral reflectance of the scene,

$I(\lambda)$ is the spectral distribution of the incident illumination, and

the k's are suitably chosen constants.

The signals e_1, e_2, and e_3 represent the most fundamental information recorded by the complete color system of Fig. 1. No contact with the "outside world" is available other than through the medium of these three quantities. The colorimetric accuracy with which they describe the original scene is basically determined by the functions $S_R(\lambda)$, $S_G(\lambda)$, and $S_B(\lambda)$.

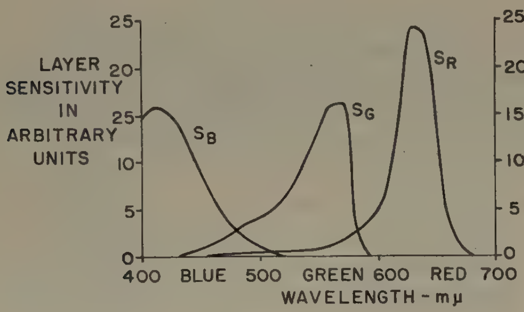


Fig. 5

In general, the signals e_1, e_2, and e_3 will not represent the original scene with colorimetric fidelity. The reason for this will be seen upon examining Fig. 5, which shows a representative set of functions for $S_R(\lambda)$, $S_G(\lambda)$, and $S_B(\lambda)$. An analysis of these curves will show that they are not a colorimetrically "proper" set of taking sensitivities in the sense that they are not linearly related to any set of color mixture curves.

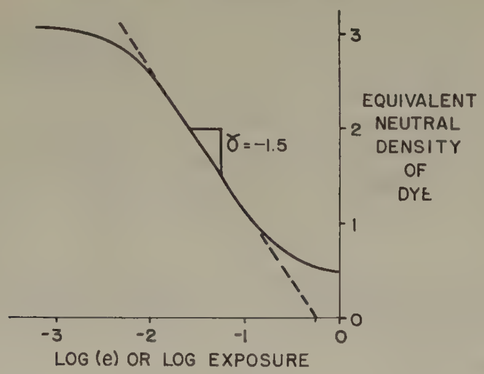


Fig. 6

The behavior of the chemical process and the reproducing dyes of Fig. 4 in relation to the signals e_1, e_2, and e_3, may be plotted as in Fig. 6. Over a substantial range of exposure and density[6] variation the transfer characteristic for each dye may be approximated by an equation of the form[3]

$$D = K + \gamma \log_{10} (e) \tag{3}$$

[6] Density $= -\log^{10}$ (Transmission).

where

D represents density (or equivalent neutral density),

K is a constant and

γ is the transfer gradient of the process evaluated as shown in Fig. 6.

As a matter of practical interest the negative slope shown in Fig. 6 arises from the fact that we are discussing a reversal type photographic process rather than the characteristics of an ordinary black and white system.

The Dye System and Photographic Crosscoupling

The characteristics of the dyes comprise an important group of parameters in the photographic process. Almost all known forms of subtractive color photography employ three colorants as reproducing primaries. In order to function as a subtractive system the dyes are usually cyan, magenta, and yellow in color and are correspondingly named. The spectral densities[7] of these three components of a typical dye system are plotted in Fig. 7. The dye concentrations shown in this diagram are adjusted so that the neutral sum of the three components has a luminous density[7] of exactly 1.0. The spectral density of the neutral sum is plotted at the top of the figure.

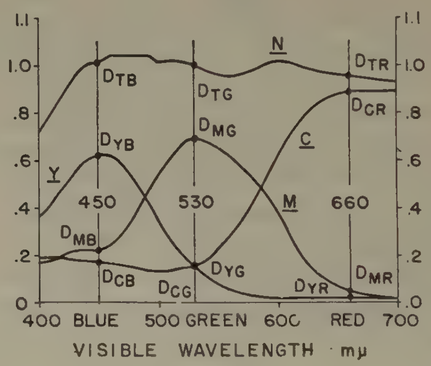


Fig. 7

These data provide an illustration of the shortcomings of most practical photographic dye systems. For example, one may measure the density of the dye mixture with a narrow band densitometer at three selected wavelengths. In the figure these are shown as lying near 450 mμ, 530 mμ, and 660 mμ;—they are chosen to correspond with the peak absorptions of the dyes. The resulting measurements will correspond to the total density points D_{TR}, D_{TG}, and D_{TB} as indicated on the neutral sum curve. In terms of the other symbols provided on the diagram it is apparent that

$$\begin{aligned} D_{TR} &= D_{CR} + D_{MR} + D_{YR} \\ D_{TG} &= D_{CG} + D_{MG} + D_{YG} \\ D_{TB} &= D_{CB} + D_{MB} + D_{YB}. \end{aligned} \tag{4}$$

[7] Color Sensitivity Subcommittee, "Principles of color sensitometry," (pamphlet), *Soc. Mot. Pict. & Telev. Eng.*, Color Sensitometry Committee; March 15, 1950.

The physical significance of the equations is simply that, for example, the total density for green light, D_{TG}, is controlled not only by the magenta density for green, D_{MG}, but also by the cyan density for green, D_{CG}, and the yellow density for green, D_{YG}. That is, each of the dyes presents attenuation to wavelengths of the spectrum which should ideally be transmitted with no attenuation at all.

In order to examine the effects of these conditions, we may rewrite (4) in terms of equivalent neutral density[7,8] That is,

$$
\begin{aligned}
D_{TR} &= a_{11}C + a_{12}M + a_{13}Y \\
D_{TG} &= a_{21}C + a_{22}M + a_{23}Y \\
D_{TB} &= a_{31}C + a_{32}M + a_{33}Y
\end{aligned} \tag{5}
$$

where C, M, and Y denote the equivalent neutral densities of the dyes. Inasmuch as the dye set of Fig. 7 is adjusted so as to produce a luminous density of exactly 1.0, the various coefficients in (5) would become:

$$
\begin{aligned}
D_{TR} &= .89C + .05M + .02Y \\
D_{TG} &= .15C + .69M + .15Y \\
D_{TB} &= .17C + .22M + .62Y.
\end{aligned} \tag{5a}
$$

The use of equivalent neutral density as a unit allows the use of the same value of transfer characteristic slope for each of the original exposure values and the corresponding dye densities. Equations (3) may therefore be substituted into (5), as follows:

$$
\begin{aligned}
D_{TR} &= \gamma(a_{11}\log e_1 + a_{12}\log e_2 + a_{13}\log e_3) \\
&\quad + K(a_{11} + a_{12} + a_{13}) \\
D_{TG} &= \gamma(a_{21}\log e_1 + a_{22}\log e_2 + a_{23}\log e_3) \\
&\quad + K(a_{21} + a_{22} + a_{23}) \\
D_{TB} &= \gamma(a_{31}\log e_1 + a_{32}\log e_2 + a_{33}\log e_3) \\
&\quad + K(a_{31} + a_{32} + a_{33}).
\end{aligned} \tag{6}
$$

Let us now define three electrical voltages e_R, e_G, and e_B as follows:

$$
\begin{aligned}
-\log e_R &= D_{TR} - K(a_{11} + a_{12} + a_{13}) \\
-\log e_G &= D_{TG} - K(a_{21} + a_{22} + a_{23}) \\
-\log e_B &= D_{TB} - K(a_{31} + a_{32} + a_{33})
\end{aligned} \tag{7}
$$

that is, we have assigned the symbols e_R, e_G, and e_B to the output signals from the narrow band densitometer and have adjusted the electro-optical conversion gains so as to cancel the effect of the fixed attenuations (densities), K.

[8] The equivalent neutral density of a given amount of one of the dyes in a subtractive set is the common logarithm of the reciprocal of the luminous transmittance of the neutral gray which can be formed with just sufficient concentrations of the other two dyes. In one sense it is a measure of the amount of neutral attenuation (gray) which may be obtained with the given amount of the dye. Under certain conditions, the equivalent neutral density of a dye is also given by the product of a constant and the spectral density of the dye at any specified wavelength. The definition of equivalent neutral density is a function of all of the dyes in the set and of the viewing illuminant.

Through substitution of (7) into (6) we have

$$
\begin{aligned}
-\log e_R &= \gamma(a_{11}\log e_1 + a_{12}\log e_2 + a_{13}\log e_3) \\
-\log e_G &= \gamma(a_{21}\log e_1 + a_{22}\log e_2 + a_{23}\log e_3) \\
-\log e_B &= \gamma(a_{31}\log e_1 + a_{32}\log e_2 + a_{33}\log e_3).
\end{aligned} \tag{8}
$$

As an example, for the dyes of Fig. 7 and the gradient of Fig. 6, (8) becomes:

$$
\begin{aligned}
-\log e_R &= -1.5(.89\log e_1 + .05\log e_2 + .02\log e_3) \\
-\log e_G &= -1.5(.15\log e_1 + .69\log e_2 + .15\log e_3) \\
-\log e_B &= -1.5(.17\log e_1 + .22\log e_2 + .62\log e_3).
\end{aligned}
$$

Equations (8) illustrate the effect of the undesired dye absorptions in a quantitative way. We should recall that the signals e_1, e_2, and e_3 constitute information describing the original scene which was initially stored within the film. However, the characteristics of the reproducing dyes are such that this original information may not be recovered from the film by any direct means without contamination. From the point of view of electronic circuits, this contamination is exactly analogous to crosscoupling. An "equivalent circuit" for the film might be drawn as in Fig. 8.

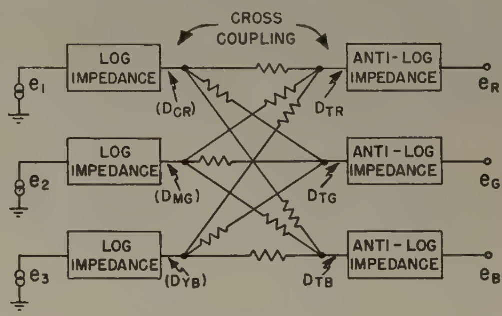


Fig. 8

The Effects of Dye Crosscoupling

With these ideas in mind we are in a position to calculate some performance data for the photographic system. For the present purposes we shall assume that the process employs the taking sensitivities of Fig. 5, the dye system of Fig. 7, and that the transfer gradient is approximately −1.5.

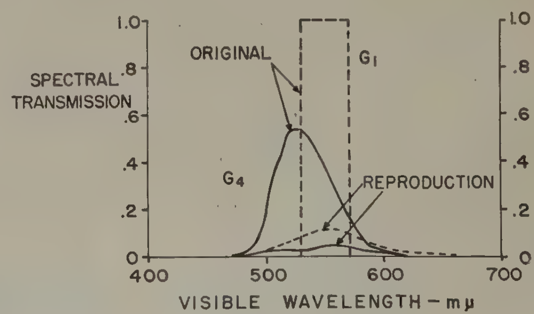


Fig. 9

In Fig. 9 we have shown the spectral characteristics of two "test colors" G_1 and G_4, together with their reproduction by the color transparency. The color G_1 is a hypothetical color, and is described by the large dashed-

line rectangle. That is, G_1 represents a material having a stimulus value of 1.0 in the region from 530 to 570 mμ. The calculated spectral characteristic of the reproduction of G_1 by the assumed process and dyes is shown as the smaller dashed-line curve. The color G_4 corresponds to the spectral transmission of a Wratten #58 filter, and is given by the upper solid curve. The lower solid curve represents the reproduction.

It is evident that in both cases a degradation has occurred. A more meaningful way of expressing this degradation involves the use of the CIE diagram as shown in Fig. 10. In this sketch the chromaticity co-ordinates of several original test colors are shown by the circled points. The numbers beside each point represent the luminance of the color on a base of 100 foot lamberts for a uniformly emitting white. The results of photographing these colors are shown by the crossed points. That is, these latter represent the calculated chromaticity co-ordinates of the corresponding color reproduction by the photographic transparency when the transparency is illuminated by an equal-energy-white source having a luminous intensity of 100 foot lamberts. It will be noted that in all cases a desaturation has occurred in the reproduction process. In addition, the luminance values of the reproduction have in all cases been degraded relative to white, and in some cases this degradation becomes substantial.

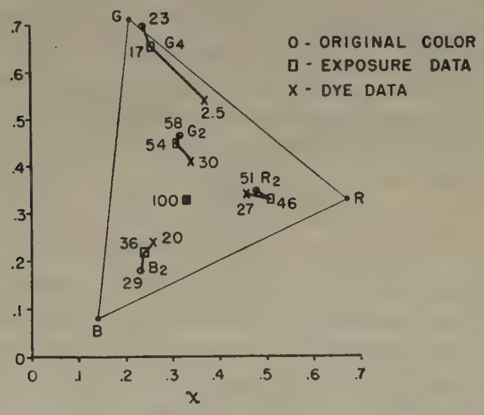


Fig. 10

Television Reproduction of the Transparency

At this juncture it appears desirable to consider the effects of this behavior upon a practical television system. We have so far assumed that the television apparatus is capable of exactly reproducing all of the points lying within the gamut shown in Fig. 10. In effect, therefore, we are assuming that the remote color receiver will display an image which is colorimetrically equivalent to a reproduction of the transparency by means of a slide projector. Since color transparencies in general have achieved a substantial commercial success, one might be led to conclude that colorimetrically accurate reproduction is in fact desirable. However, an examination of *practical* television apparatus immediately reveals a wide disparity between the available luminance range of the television reproducer and that of the photographic process. For example a contrast ratio of perhaps 20:1 represents a reasonable value for a present-day color television display. However, a contrast ratio of 100:1 or more may be realized with the photographic process. For these conditions, Fig. 10 indicates that the photographic reproduction of the color G_4 is too low in luminance to be rendered properly by the television system. Nevertheless, experience indicates that direct optical projection of the transparency will yield a usable result.

Let us now consider the question which forms the basis for the present discussion. We have outlined briefly the modes of operation of the photographic process and of the television system. We have seen that certain color degradations are introduced into the complete color system of Fig. 1 and that these degradations are largely due to the behavior of the photographic dye system. It now appears desirable to attempt to adjust the television system so as to offset partially the effects of the photographic process.

One possible method of performing this adjustment involves the use of the rectangular data points in Fig. 10. These chromaticity co-ordinates represent the color reproduction which would have been obtained if the "voltages" e_1, e_2, and e_3, were applied directly to the reproducing primaries of a color television display operating in accordance with our previous specifications. It is immediately apparent from the diagram that, although the taking sensitivities $S_R(\lambda)$, $S_G(\lambda)$, and $S_B(\lambda)$ are not a "proper set," the color reproduction arising from the use of these sensitivities directly is superior to that obtained from the dye system. In particular, the saturation and luminance errors for most of the test colors are somewhat reduced.

In order to realize the colorimetric performance shown by the rectangular points of Fig. 10 it becomes necessary for us to recover the voltages e_1, e_2, and e_3 within the television part of the system and to substitute them for the voltages e_R, e_G, and e_B of Fig. 1.

We may begin by adjusting the functions $T_R(\lambda)$, $T_G(\lambda)$, and $T_B(\lambda)$ in (1) so that e_R, e_G, and e_B are given by (7). That is

$$
\begin{aligned}
-\log e_R &= D_{TR} - K(a_{11} + a_{12} + a_{13}) \\
-\log e_G &= D_{TG} - K(a_{21} + a_{22} + a_{23}) \qquad (7) \\
-\log e_B &= D_{TB} - K(a_{31} + a_{32} + a_{33}).
\end{aligned}
$$

This is equivalent to substituting the television system for the narrow band densitometer which we have previously described. Through this substitution we have effectively connected the network of Fig. 8 as the input element to the television system.

The relationship between the desired signal voltages e_1, e_2, e_3, and the television system voltages has been

given in (8). Through the use of determinants it is possible to write the inverse of (8) as follows:

$$
\begin{aligned}
-\log e_1' &= 1/\gamma(k_{11}\log e_R + k_{12}\log e_G + k_{13}\log e_B)\\
-\log e_2' &= 1/\gamma(k_{21}\log e_R + k_{22}\log e_G + k_{23}\log e_B) \quad (9)\\
-\log e_3' &= 1/\gamma(k_{31}\log e_R + k_{32}\log e_G + k_{33}\log e_B)
\end{aligned}
$$

where the primed notation is intended to distinguish the derived signals from the original signals.

Again referring to the dye system of Fig. 7 these equations become:

$$
\begin{aligned}
-\log e_1' &= \frac{1}{-1.5}(1.14\log e_R - .08\log e_G\\
&\quad - .02\log e_B)\\
-\log e_2' &= \frac{1}{-1.5}(-.20\log e_R + 1.58\log e_G \quad (9a)\\
&\quad - .38\log e_B)\\
-\log e_3' &= \frac{1}{-1.5}(-.24\log e_R - .54\log e_G\\
&\quad + 1.75\log e_B).
\end{aligned}
$$

The electrical equivalent of (9) is a circuit identical in form with that shown in Fig. 8. Such a network may be constructed and inserted into the television system as indicated by Fig. 11. In this diagram the letter Z denotes the original crosscoupling network described by (8). The symbol $1/Z$ is assigned to the inverse operation. The voltages e_1', e_2', and e_3' are therefore identical in form with the original signals e_1, e_2, and e_3 over the range for which (8) are valid. As a result the color reproduction from the system may be expected to approximate the rectangular data points of Fig. 10 for the indicated test colors.

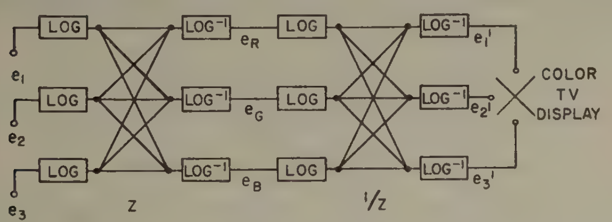


Fig. 11

Equivalence with Photographic Masking

The ideas we have discussed in the preceding paragraphs represent the electronic equivalent of photographic masking.[9,10] That is, an inspection of (9) will show that they may be rewritten in the following form:

$$
\begin{aligned}
-\log e_1' &= -\log e_R + 1/\gamma([k_{11}+\gamma]\log e_R\\
&\quad + k_{12}\log e_G + k_{13}\log e_B)\\
-\log e_2' &= -\log e_G + 1/\gamma(k_{21}\log e_R \quad (10)\\
&\quad + [k_{22}+\gamma]\log e_G + k_{23}\log e_B)\\
-\log e_3' &= -\log e_B + 1/\gamma(k_{31}\log e_R\\
&\quad + k_{32}\log e_G + [k_{33}+\gamma]\log e_B).
\end{aligned}
$$

In other words, the signal $\log e_1$, for example, is derived by the addition of a "mask image" drawn from all three channels to the main signal, $\log e_R$, in the red channel.

Exact Duplication

There is an additional consequence of this mode of operation which may be of some interest. Let us assume for the moment that the spectral characteristics of the television reproducing primaries are chosen in such a way that each one of the lights would be perceived by only one of the three emulsion layers which constitute the input "connections" to the photographic process, and that the "observer" in Fig. 1 is replaced by a sheet of unexposed film. Upon reference to Fig. 5, for example, it is apparent that a choice of primaries composed of three narrow bands of energy in the vicinity of 420 mμ, 540 mμ, and 630 mμ would allow almost independent control of the three emulsions. The selective exposures received by the film which replaces the observer would then be in accordance with the signals e_1', e_2', and e_3', as shown in Fig. 11. The resulting exposure record within the film would then be identical with that of the original transparency. Processing the material would therefore give rise to a set of dye distributions which were also identical with those of the original transparency. By this means a so-called "exact duplicate" of the original might be obtained.

An Approximate Solution for Practical Apparatus

As is frequently the case the practical realization of electronic masking involves certain apparatus difficulties. The first of these resides in the requirement for the use of logarithmic impedances in order to obtain an exact solution for the desired signal voltages. Since logarithmic impedances are somewhat difficult to realize when a wide frequency range is involved, it would be advantageous if their use could be avoided by means of an approximate solution.

It will prove convenient to define a set of differential voltages as follows:

$$
\begin{aligned}
e_R &= 1 + \Delta e_R\\
e_G &= 1 + \Delta e_G \quad (11)\\
e_B &= 1 + \Delta e_B
\end{aligned}
$$

and so on.

Rewriting the first member of (8) in terms of this notation we have:

$$
\begin{aligned}
-\log(1+\Delta e_R) &= \gamma[a_{11}\log(1+\Delta e_1)\\
&\quad + a_{12}\log(1+\Delta e_2) + a_{13}\log(1+\Delta e_3)]. \quad (12)
\end{aligned}
$$

An expansion of (12) by means of Taylor's series may

[9] Neblette, *loc. cit.*, pp. 471–481.
[10] T. H. Miller, "Masking: A technique for improving the quality of color reproductions," *Jour. Soc. Mot. Pict. & Telev. Eng.*, pp. 133–155; February, 1949.

be written as follows:

$$-\Delta e_R+\frac{(\Delta e_R)^2}{2}-\frac{(\Delta e_R)^3}{2}+\cdots$$
$$=\gamma(a_{11}\Delta e_1+a_{12}\Delta e_2+a_{13}\Delta e_3) \qquad (13)$$
$$-\gamma\left(\frac{a_{11}(\Delta e_1)^2}{2}+\frac{a_{12}(\Delta e_2)^2}{2}+\frac{a_{13}(\Delta e_2)^2}{2}\right)+\cdots .$$

It will be seen that if the voltage increments are sufficiently small all those terms of higher than first order may be discarded. For all three members of (8) we may therefore write:

$$\begin{aligned} -\Delta e_R &= \gamma(a_{11}\Delta e_1 + a_{12}\Delta e_2 + a_{13}\Delta e_3) \\ -\Delta e_G &= \gamma(a_{21}\Delta e_1 + a_{22}\Delta e_2 + a_{23}\Delta e_3) \qquad (14) \\ -\Delta e_B &= \gamma(a_{31}\Delta e_1 + a_{32}\Delta e_2 + a_{33}\Delta e_3). \end{aligned}$$

Equations (14) represent a first order approximation for small signal variations to the behavior of the photographic process. It is instructive to think of the various coefficients as representative of electrical "gains." That is, one might say that the "gain" from the input channel carrying e_2 into the output channel for e_R is equal in magnitude to a_{12}, and so on.

As in the case of (8), (14) may be inverted to form

$$\begin{aligned} -\Delta e_1' &= 1/\gamma(k_{11}\Delta e_R + k_{12}\Delta e_G + k_{13}\Delta e_B) \\ -\Delta e_2' &= 1/\gamma(k_{21}\Delta e_R + k_{22}\Delta e_G + k_{23}\Delta e_B) \qquad (15) \\ -\Delta e_3' &= 1/\gamma(k_{31}\Delta e_R + k_{32}\Delta e_G + k_{33}\Delta e_B). \end{aligned}$$

Also

$$\begin{aligned} -e_1' &= -e_R + 1/\gamma[(k_{11}+\gamma)e_R + k_{12}e_G + k_{13}e_B] \\ -e_2' &= -e_G + 1/\gamma[k_{21}e_R + (k_{22}+\gamma)e_G + k_{23}e_B] \qquad (16) \\ -e_3' &= -e_B + 1/\gamma[k_{31}e_R + k_{32}e_G + (k_{33}+\gamma)e_B]. \end{aligned}$$

It must be emphasized that (16) are valid only for small signal variations. However, the electrical operations indicated by (16) may be incorporated with ease into a practical television system for an experimental evaluation.

An Example of a Practical Solution

Equations (16) describe a linear equivalent of the electrical network of the type shown in Fig. 11. The physical realization of this network requires the evaluation of the various constants, and involves a second practical apparatus difficulty. As we have already shown, such an evaluation will be completely straightforward when the conditions placed upon the evaluation of density in (4) are such that D_{TR}, D_{TG}, and D_{TB} are specified for particular spectral wavelengths. This implies that the measuring device accepts radiant energy only over limited portions of the spectrum and may constitute a hardship for certain types of television pickup apparatus. That is, poor "optical efficiency" may lead to an unsatisfactory signal-to-noise ratio.

In order to avoid this difficulty it becomes desirable to introduce an additional approximation into the masking operation. More particularly, it is desirable that the functions $T_R(\lambda)$, $T_G(\lambda)$, and $T_B(\lambda)$ be chosen so as to obtain a reasonable value of optical efficiency within the television system.

A particular set of $T_R(\lambda)$, $T_G(\lambda)$, $T_B(\lambda)$ which we shall use as an example in computing the several constants is shown in Fig. 12. These taking sensitivities are typical of the characteristics which may be expected from some types of flying spot slide scanners.

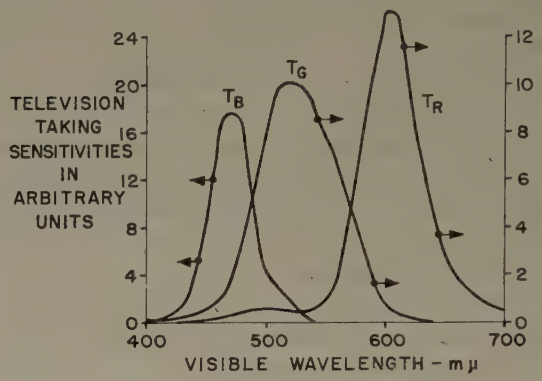


Fig. 12

Let us now assume that $R(\lambda)$ in (2) is adjusted to a uniformly reflecting gray, $R_0(\lambda)$, such that

$$\begin{aligned} e_1 &= k_1\int_{400}^{700} S_R(\lambda)R_0(\lambda)I_0(\lambda)d\lambda = .2155 \\ e_2 &= k_2\int_{400}^{700} S_R(\lambda)R_0(\lambda)I_0(\lambda)d\lambda = .2155 \qquad (17) \\ e_3 &= k_3\int_{400}^{700} S_R(\lambda)R_0(\lambda)I_0(\lambda)d\lambda = .2155 \end{aligned}$$

that is, the "exposure reflectance" of the scene is .2155.

Therefore, from (3) the equivalent neutral densities of the dyes become

$$\begin{aligned} C &= K - 1.5(\log e_1) = K + 1.0 \\ M &= K - 1.5(\log e_2) = K + 1.0 \qquad (18) \\ Y &= K - 1.5(\log e_3) = K + 1.0. \end{aligned}$$

By computing the sum $C+M+Y$ for every wavelength of the spectrum in accordance with the dye characteristics of Fig. 7 we may obtain the spectral transmission of the resultant color transparency. This curve corresponds to that labeled $H_0(\lambda)$ in Fig. 13, and is identical with the neutral sum curve in Fig. 7.

We will now proceed to vary the reflectance of the scene by a differential amount in various regions of the spectrum so that we obtain the following signals and equivalent neutral densities from (17) and (18):

Scene Condition	e_1	e_2	e_3	C	M	Y	Name
$R_0(\lambda)$	.2155	.2155	.2155	1.0	1.0	1.0	$H_0(\lambda)$
$R_1(\lambda)$	.2512	.2155	.2155	0.9	1.0	1.0	$H_1(\lambda)$
$R_2(\lambda)$	.2155	.2512	.2155	1.0	0.9	1.0	$H_2(\lambda)$
$R_3(\lambda)$	.2155	.2155	.2512	1.0	0.1	0.9	$H_3(\lambda)$

Fig. 13 provides a plot of the spectral transmission of the color transparency corresponding to one of these assumed scene variations, i.e., $H_1(\lambda)$. For convenience these spectral distributions will be named $H_0(\lambda)$, $H_1(\lambda)$, $H_2(\lambda)$, and $H_3(\lambda)$.

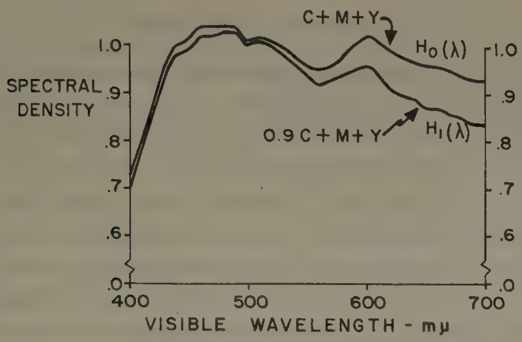


Fig. 13

From these data we may evaluate a group of integrals of the form shown by (1). In tabular form the results are as follows:

Integral for	Spectral Distribution			
	$H_0(\lambda)$	$H_1(\lambda)$	$H_2(\lambda)$	$H_3(\lambda)$
e_R	.1022	.1181	.1103	.1026
e_G	.1011	.1058	.1156	.1054
e_B	.0940	.0974	.1016	.1056

Sufficient information is now available to evaluate the constants in (14). Referring to these expressions it will be noted that if Δe_2 and Δe_3 are zero then,

$$\gamma a_{11} = \frac{-\Delta e_R}{\Delta e_1}, \qquad \gamma a_{21} = \frac{-\Delta e_G}{\Delta e_1}, \qquad \gamma a_{31} = \frac{-\Delta e_B}{\Delta e_1},$$

and so on. The differential signals may be obtained from the data we have tabulated above. That is

$$\gamma a_{11} = \frac{-\Delta e_R}{\Delta e_1} = \frac{.1181 - .1022}{.2512 - .2155} = \frac{.0159}{.0357} = 0.45$$

$$\gamma a_{12} = \frac{-\Delta e_R}{\Delta e_2} = \frac{.1103 - .1022}{.2512 - .2155} = \frac{.0081}{.0357} = 0.23$$

$$\gamma a_{13} = \frac{-\Delta e_R}{\Delta e_3} \doteq \frac{.1026 - .1022}{.2512 - .2155} = \frac{.0004}{.0357} = 0.01$$

and so on. Therefore (14) becomes

$$\begin{aligned} \Delta e_R &= .45\Delta e_1 + .23\Delta e_2 + .01\Delta e_3 \\ \Delta e_G &= .13\Delta e_1 + .41\Delta e_2 + .12\Delta e_3 \\ \Delta e_B &= .10\Delta e_1 + .21\Delta e_2 + .33\Delta e_3. \end{aligned} \tag{14a}$$

Solving (14a) we have:

$$\begin{aligned} \Delta e_1' &= 2.60\Delta e_R - 1.75\Delta e_G + .55\Delta e_B \\ \Delta e_2' &= -.77\Delta e_R + 3.51\Delta e_G - 1.32\Delta e_B \\ \Delta e_3' &= -.29\Delta e_R - 1.79\Delta e_G + 3.70\Delta e_B. \end{aligned} \tag{15a}$$

For reasons relating to the construction and control of practical apparatus it is convenient to rewrite (15a):

$$\begin{aligned} \Delta e_1'/1.40 &= \Delta e_R + 1.1/40(1.20\Delta e_R \\ &\quad - 1.75\Delta e_G + .55\Delta e_B) \\ \Delta e_2'/1.42 &= \Delta e_G + 1/1.42(2.09\Delta e_G \\ &\quad - .77\Delta e_R - 1.32\Delta e_B) \\ \Delta e_3'/1.62 &= \Delta e_B + 1/1.62(2.08\Delta e_B \\ &\quad - .29\Delta e_R - 1.79\Delta e_B). \end{aligned} \tag{16a}$$

It will be noted that the masking signals in (16a) are essentially equivalent to color-difference signals. In particular, when $e_R = e_G = e_B$ the masks vanish.

A block diagram of an apparatus arrangement which will realize the conditions for the two lower members of (16a) is shown in Fig. 14. (The red signal channel apparatus assumes a slightly different form because of the positive sign in the coefficient for e_B.) This circuit arrangement is intended to be inserted into the television system immediately following the electrical outputs of the television pickup device and prior to any gamma correction which may be required in a practical system. However, to the extent that the gamma correction circuits approximate the nonlinear operations required for an exact solution of (8), it is possible that the apparatus performance might be improved by inserting it into the system *after* gamma correction.

Calculated Performance

The preceding paragraphs have shown that this apparatus arrangement represents no more than an approximation to the ideal conditions in at least two respects. In the first place the circuit operation is valid only for small signal variations inasmuch as a linear approximation to (8) has been employed. In the second place, the use of wide band taking sensitivities for the television apparatus introduces an additional error into the process of evaluating the dye concentrations.

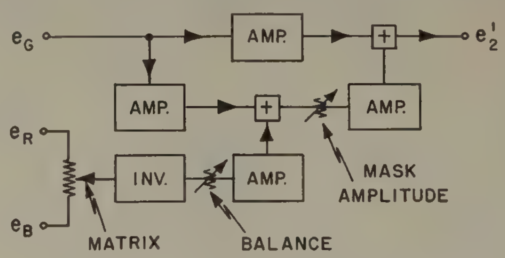


Fig. 14

However, a series of calculations of the apparatus performance has been made. The results are shown in Fig. 15. In this diagram we again make use of the CIE chromaticity diagram for the display of colorimetric data. The initial test colors are once again shown as circular data points, as in Fig. 10 The rectangular points represent the calculated reproduction of these test colors by the complete color system of Fig. 1 when the taking sensitivities of Fig. 12 are employed without the use of electronic masking. The crossed data points represent the calculated effect of introducing the masking circuitry of Fig. 14.

It will be noted that even though the television taking sensitivities of Fig. 12 are not a colorimetrically "proper"

set, the rectangular points in Fig. 15 correspond closely with the crossed points of Fig. 10. That is, the errors due to the television system taking sensitivities are sub-

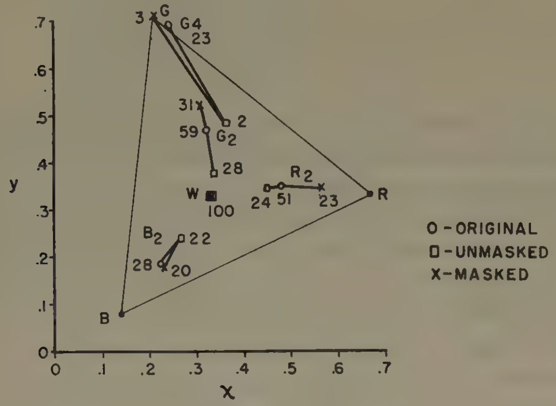


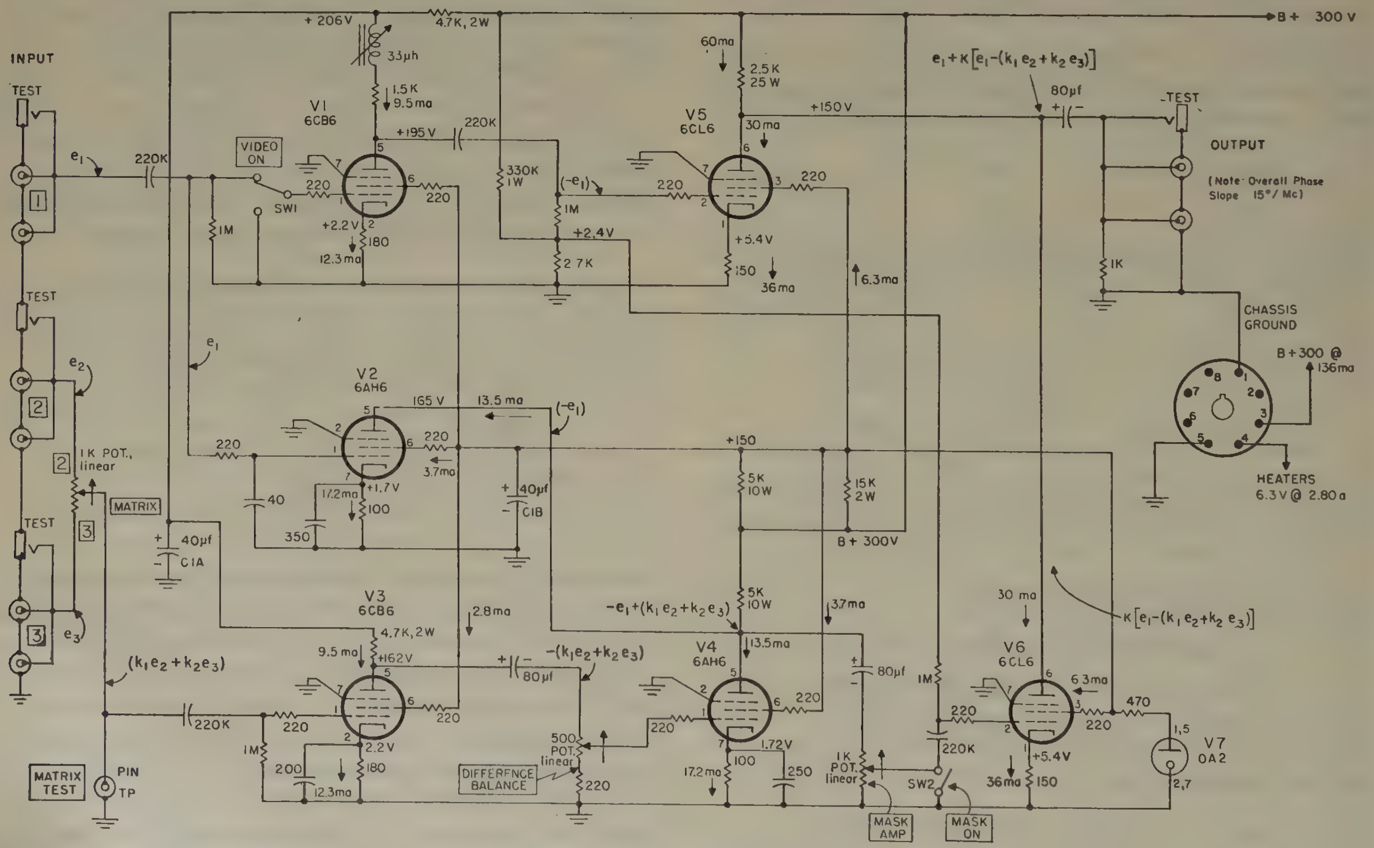
Fig. 15

stantially less than those introduced by the dye characteristics of the photographic process.

The luminance values beside the crossed points in Fig. 15 indicate that the linear approximation has essentially no corrective effect upon the luminance errors of the reproduction. However, the saturation of all of the test colors is considerably increased when the mask is connected into the circuit. In most cases the masking operation actually increases the saturation of the reproduction beyond that of the original. For the color B_2, the chromaticity error of the reproduction is substantially eliminated.

Laboratory Results

Practical laboratory experience with electronic masking has been obtained with two units of the type shown in Fig. 14. The schematic circuit of these units is given in Fig. 16. This equipment was constructed prior to completion of the work presented in this paper and was connected to a laboratory-type flying-spot scanner. At that time it was assumed that no significant correction would be required for the red signal channel hence this unit was omitted. The available correction was therefore intended to deal primarily with the nonideal behavior of the cyan and magenta dyes in the blue and green regions of the spectrum. However, in spite of the omission of the third unit, preliminary practical results have been satisfactory. There appears to be substantial agreement among observers to the effect that the subjective value of the reproduced images is enhanced when the masking arrangements are connected into the circuit of the units.



ma = milliamperes; K = 1000; M = megohms.
All values are in ohms and micro micro farads, unless otherwise specified.

Fig. 16

Matrix Networks for Color TV*

WILLIAM R. FEINGOLD†, ASSOCIATE, IRE

Summary—This paper indicates four techniques whereby the algebraic manipulations required in a color television transmitter or receiver may be accomplished. Two of these are simple summation procedures, i.e., a common plate and a common cathode-load; two are weighted summations, i.e., a feedback and a passive network.

Introduction

THE addition of color to television brings with it the additional complexity of simple summation type circuits. Although the computer art has investigated and produced a wide range of circuits capable of performing many varied functional operations, it is not likely that the television designer is familiar with them. For our purpose we will discuss only simple and weighted summations that are capable of producing a sum from two or three independent parameters.

The NTSC signal specifications indicate that the transmitter gear shall be capable of the following computations:

$$E_y' = 0.30E_R' + 0.59E_G' + 0.11E_B' \quad (1)$$

$$E_Q' = 0.41(E_B' - E_y') + 0.48(E_R' - E_y) \quad (2)$$

$$= 0.21E_R' - 0.53E_G' + 0.31E_B' \quad (3)$$

$$E_I' = -0.27(E_B' - E_y') + 0.74(E_R' - E_y') \quad (4)$$

$$= 0.59E_R' - 0.28E_G' - 0.32E_B'. \quad (5)$$

Typical operations to be performed in the receiver are:[1]

$$E_B' = -1.11E_I' + 1.72E_Q' + 1.00E_y' \quad (6)$$

$$E_G' = -0.28E_I' - 0.64E_Q' + 1.00E_y' \quad (7)$$

$$E_R' = +0.96E_I' + 0.63E_Q' + 1.00E_y'. \quad (8)$$

Simple Summation—Common Plate Load

Simple summations are the type that perform a simple totalization (ignoring phase inversion), i.e.—

$$\sum E = E_1 + E_2 + E_3 + \cdots + E_n. \quad (9)$$

This means that if we apply this thinking to (1), for instance, it is first necessary that we modify E_R', E_G', and E_B' in accordance with their respective constants prior to the application of (9).

One technique for performing a simple summation is to use a common plate load[2] as shown in Fig. 1. On the premise that "n" identical tubes are used it can be shown that the output voltage is:

$$E_0 = \frac{-\mu}{1+\dfrac{r_p[r_b+R_L(n-1)]}{R_L r_b}}(E_1+E_2+\cdots+E_n). \quad (10)$$

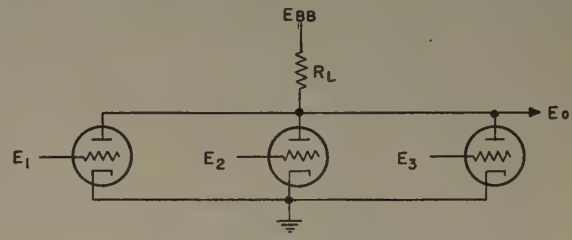


Fig. 1—Common plate load.

Note that this formulation contains the unexpected parameter r_b, the dc plate resistance of the tube. Manipulating (10) yields an interesting result, as follows:

Expand the denominator:

$$E_0 = \frac{-\mu}{1+\dfrac{r_p}{R_L}+\dfrac{r_p(n-1)}{r_b}}(E_1+E_2+\cdots+E_n). \quad (11)$$

Factor out r_p

$$E_0 = \frac{-\mu}{r_p\left(\dfrac{1}{r_p}+\dfrac{1}{R_L}+\dfrac{n-1}{r_b}\right)}(E_1+E_2+\cdots+E_n) \quad (12)$$

$$E_0 = -G_m R_L'(E_1+E_2+\cdots+E_n), \quad (13)$$

where a modified plate load R_L' is:

$$\frac{1}{R_L'} = \frac{1}{r_p} + \frac{1}{R_L} + \frac{n-1}{r_b}. \quad (14)$$

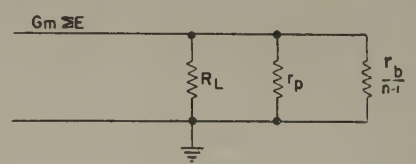


Fig. 2—Equivalent circuit for common plate load.

Fig. 2 indicates the equivalent circuit described by (13). Two important points are worth noting. The shunting effect of $r_b/(n-1)$ is an important factor in many cases. The gain per tube can be seriously affected by this branch. In a 3-tube video matrix with R_L and r_b equal to 5000 ohms, the gain per tube will be one third of the gain of a one-tube amplifier. If the matrix requires some video peaking, this shunting branch will effectively

* Decimal classification: R583. Original manuscript received by the Institute, August 28, 1953.

† Emerson Radio and Phono. Corp., New York, N. Y.

[1] G. H. Brown and D. G. C. Luck, "Principles and development of color TV systems," *RCA Review*, June, 1953.

[2] Samuel Seely, "Electron Tube Circuits," McGraw Hill, First Edition, chap. 8, p. 146; 1950.

nullify any form of shunt peaking. Simple series peaking will usually be the most desirable compensation for this particular circuit.

Note that the accuracy of the final summation indicated in (13) is predicated on all the tubes having identically equal parameter values. This is usually not the case, hence small degenerate cathode potentiometers are usually required to establish equalization of gain.

Common Cathode

Fig. 3 indicates a summation circuit utilizing a common cathode resistor. The result here is similar to the common plate resistor except that no phase inversion occurs. It can be shown[3] that

$$E_0 = \frac{\mu R_k}{n(\mu+1)R_k + r_p}(E_1 + E_2 + \cdots + E_n) \quad (15)$$

$$= \frac{\mu}{n(\mu+1) + \dfrac{r_p}{R_k}}(E_1 + E_2 + \cdots + E_n). \quad (16)$$

If $\mu > 20$
$R_k \geqq r_p$
—a close approximation is—

$$E_0 = \frac{1}{n}(E_1 + E_2 + \cdots + E_n). \quad (17)$$

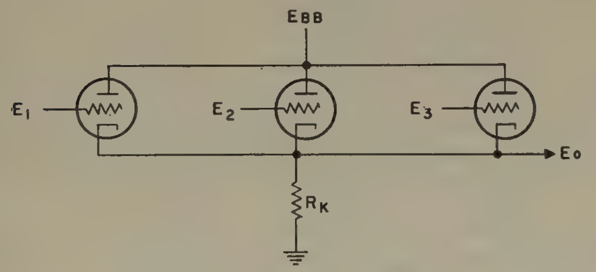


Fig. 3—Common cathode.

From the point of view of gain this circuit is notoriously inefficient. For a three-tube array the gain per tube is 0.33. The allowable dynamic range per tube is reduced because each tube is driving into the low impedance of the remainder of the group. This low impedance however means that the matrix has excellent frequency and transient response. Note too that this system is capable of a precision matrix operation since (17) is devoid of tube parameters. This statement is still valid even if u and r_p of the tube do not conform to the limitations above. The total effect would be to modify E_0 by some constant in range of 0.9 to 1.0.

Weighted Summations

The weighted summation is different from a simple summation in that the final result produced is not just the sum of the individual input voltages but the sum of each of these input voltages modified by a desired factor. For instance, if we examine (1), the properly designed weighted summation matrix would produce an output E_y' if the individual voltages E_R', E_G', and E_B' were fed into the system.

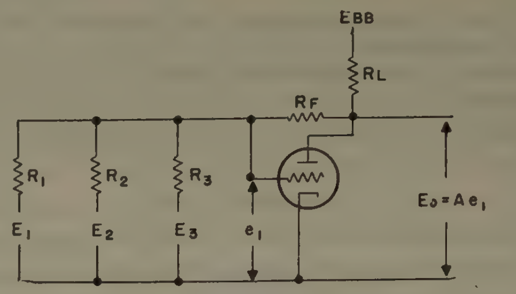


Fig. 4—Feedback summation.

Feedback Summation

A very popular form of this circuit is shown in Fig. 4. It can be shown[4,5] that the output voltage is

$$E_0 = \frac{-\left(\dfrac{E_1}{R_1} + \dfrac{E_2}{R_2} + \cdots + \dfrac{E_n}{R_n}\right)}{\dfrac{1}{R_F} - \dfrac{\left(\dfrac{1}{R_1} + \dfrac{1}{R_2} + \cdots + \dfrac{1}{R_n}\right) + \dfrac{1}{R_F}}{A}} \quad (18)$$

where A is the tube gain. If $A > 6n$ (18) can be reduced to:

$$E_0 = -R_F\left(\frac{E_1}{R_1} + \frac{E_2}{R_2} + \cdots + \frac{E_n}{R_n}\right) \quad (19)$$

$$E_0 = -\left(\frac{R_F}{R_1}E_1 + \frac{R_F}{R_2}E_2 + \cdots + \frac{R_F}{R_n}E_n\right). \quad (20)$$

If we set $R_1 = R_2 = R_n = R_F$ then (20) reduces to a simple summation. To set up weighted factors we must first recognize that R_F is an independent parameter, and assign it some arbitrary value. It is then possible to calculate the required values of R_1R_2, and R_3 by recognizing the particular constants of (1) through (8) that are applicable. By this means it is possible to exactly reproduce (1) through (8). Note that it is possible to effect a gain in the system by increasing the value of R_F after R_1, R_2, and R_3 have been calculated. This move increases the magnitude of E_0 without changing the desired ratio between the various terms in the equation. The fact that (19) was obtained by assuming that A, the tube gain, was a particularly high value in no way weakens the ratio between the terms of (20). Acknowledging the actual value of A only effects the total magnitude of E_0. It is possible to produce a precision matrix operation by selecting precise resistor components as tube parameters do not appear in (20).

[3] See reference 2.

[4] See reference 2.

[5] "Waveforms," Radiation Lab Series, vol. 19, chap. 18, McGraw Hill Book Co., Inc., New York, N. Y.; 1949.

Because the input impedance at the grid is very small, approximately $(1-A)/R_F$, the input impedance presented to each source is simply its series resistor. Consequently the system has excellent frequency and transient response for moderately large values of resistor. The one limiting factor in establishing a precision matrix is the realization that the value of the series resistors, as used in these calculations, must also include the source resistances. These sources impedances should be small enough so that any variation in their magnitude will not materially affect the accuracy of the over-all operation.

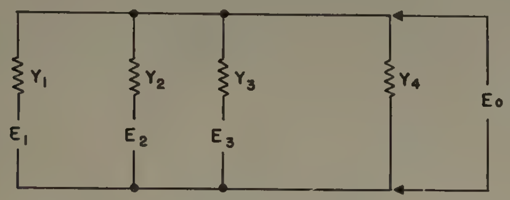


Fig. 5—Passive summation.

Passive Summation

The passive summation[6] shown in Fig. 5 contains no vacuum tubes and is an attractive arrangement where law impedance driving sources are available. The solution is straightforward:

$$E_0Y_4 = Y_1(E_1 - E_0) + Y_2(E_2 - E_0) + Y_3(E_3 - E_0) \quad (21)$$

$$0 = Y_1E_1 + Y_1E_2 + Y_3E_3 - E_0(Y_1 + Y_2 + Y_3 + Y_4) \quad (22)$$

$$E_0 = \frac{Y_1E_1}{\sum Y} + \frac{Y_2E_2}{\sum Y} + \frac{Y_3E_3}{\sum Y}. \quad (23)$$

The application of (23) to the requirements of (1), for instance, requires that we recognize a number of interesting points about (23). First, the parameter Y_4 is a fourth unknown that may run the gamut from zero to very large values without destroying the ratio between the terms of (23). We could probably assume that Y_4 were zero and proceed to apply a determinant solution to the remainder but we would find that the resulting resistors would be too large to produce an acceptable band pass even with compensation.

One simple method of approach is to forget the absolute constants of the desired equation and concentrate only on their ratio.

If, in (1) we let

$$E_1 = E_R' \quad (24)$$

$$E_2 = E_G' \quad (25)$$

$$E_3 = E_B', \quad (26)$$

then we may write

$$\frac{Y_1}{\sum Y} = 0.30 \quad (27)$$

[6] See reference 5.

$$\frac{Y_2}{\sum Y} = 0.59 \quad (28)$$

$$\frac{Y_3}{\sum Y} = 0.11. \quad (29)$$

Taking ratios, we have

$$\frac{Y_1}{Y_2} = \frac{0.30}{0.59} = 0.509 \quad (30)$$

$$\frac{Y_2}{Y_3} = \frac{0.59}{0.11} = 5.36 \quad (31)$$

$$\frac{Y_3}{Y_1} = \frac{0.11}{0.30} = 0.367. \quad (32)$$

Let

$$R_4 = R_2 = 2.50K.$$

Then

$$R_1 = \frac{2.5}{0.509} = 4.91K \quad (33)$$

$$R_3 = 2.5(5.36) = 13.4K. \quad (34)$$

Applying these values to (23)

$$E_0 = 0.189E_R' + 0.371E_G' + 0.069E_B', \quad (35)$$

so

$$E_0 = 0.630E_Y' = 0.630[0.30E_R' + 0.59E_G' + 0.11E_B']. \quad (36)$$

The resulting matrix has a gain of 0.63. It is possible to raise this figure by increasing R_4 but the benefit will be slight and the loss to the bandwidth great. With the figures used it is possible to achieve wide-band performance with the use of small trimmer capacitors across the elements to effect the required capacitance division. Although it is obvious why R_4 was arbitrarily selected, the reason R_2 was also selected (any one of the remaining three could have been chosen) may not be obvious. An examination of (1) shows that this element would be the smallest resistor, hence it was selected equal to R_4.

Since the resistance values include the source resistances it is desirable that these be kept small. This would not be necessary if the source resistance could be fixed to an accurate value but considering the wide tolerance that exist in tube parameters the accepted technique is to feed the matrix from cathode followers having about 100 ohms of source impedance.

Conclusion

This article has set down the matrixing operations required by the color transmitter and receiver. Four typical circuits that can perform the necessary operations have been discussed, theoretically and practically in such a manner that the design engineer should have no difficulty in applying the principles set forth.

The Colorplexer—A Device for Multiplexing Color Television Signals in Accordance with the NTSC Signal Specifications*

E. E. GLOYSTEIN†, ASSOCIATE, IRE, AND A. H. TURNER†, ASSOCIATE, IRE

Summary—**The color signal specifications proposed by the National Television System Committee are discussed in so far as they apply to the RCA transmitter colorplexer. The principal colorplexer functions of matrixing, band limiting, and delay correction, modulating, burst generating, and mixing are described in considerable detail. Wave forms, photographed at several points in the colorplexer, are shown for one standard color-bar signal.**

Introduction

It is the purpose of this paper to describe an encoding or multiplexing device which produces a color television signal suitable for broadcast service to home receivers. Color television involves a multiplexing problem, because the additive, three primary color reproducing process upon which color television is founded requires the transmission of three independent signals to control the red, green, and blue primary images at the receiver. When the FCC established the criterion that a system of color television for broadcast use must operate within a six-megacycle channel (the same as for monochrome service), it became evident that some multiplexing means must be employed to permit the transmission of red, green, and blue video signals through a single transmission channel without cross talk. In order to make possible the initiation of a color television broadcast service under the economic conditions prevailing in the broadcast industry, it soon became evident to most television engineers that the color system used for broadcasting should be compatible with the existing monochrome system, so that color telecasts could provide normal service to the millions of black-and-white viewers. Furthermore, it became understood by television engineers that the color television system should be so set up that it makes the best possible use of the frequency spectrum, since extra information must now be transmitted in the same channel formerly used only to transmit monochrome or luminance information. This meant, in particular, that the signal to be broadcast should contain no superfluous information that cannot be utilized by the human eye.

In 1949 the Radio Corporation of America announced the development of a color television system which it felt was potentially capable of providing a satisfactory broadcast service to the American people. The basic principles used in the RCA system have remained essentially unchanged since that time. However, the exact composition of the signal techniques has undergone some evolution as a result of the work of the National Television System Committee. The present signal specifications, those submitted to the FCC for approval in July, 1953, have almost unanimous support in the industry.

Two relatively distinct operations are employed in the RCA color television system to process the red, green, and blue primary video signals for transmission. First, the signals are cross-mixed, or matrixed, to produce a luminance signal, which will be designated by M since it is equivalent to an ordinary monochrome signal, and two color-difference or chrominance signals, which will be designated by I and Q. The luminance signal is produced by adding the three primary color signals in the ratio of 59% green, 30% red, and 11% blue (these numbers are proportioned to the relative luminosities of unit amounts of the primaries). The two chrominance signals may also be expressed as functions of red, green, and blue in accordance with the following equations:

$$I = 0.60R - 0.28G - 0.32B$$

$$Q = 0.21R - 0.52G + 0.31B.$$

The two chrominance signals in combination indicate how the color being transmitted differs from a neutral or gray of the luminance indicated by the luminance signal. Note that for all neutral colors, such that $R=G=B$, both I and Q go to zero.

The reason for performing the matrix operation in the RCA color system is twofold. The compatibility requirement is satisfied by producing a luminance signal comparable to the signal transmitted in an ordinary monochrome system, and the requirement for optimum spectrum utilization can be met by proper choice of chrominance signals. It is now a well established fact that the acuity of the human eye (i.e., its ability to resolve fine detail) is considerably greater for brightness differences than for hue and saturation differences. Consequently, it is not necessary to transmit chrominance signals (which control only hue and saturation, to a first degree of approximation) with the same bandwidth (nominally 4 megacycles) normally allotted to the luminance signal. Careful study of human vision has

* Decimal classification: R583. Original manuscript received by the Institute, November 6, 1953.

† Radio Corp. of America, TV Camera Equipment Group, Camden, N. J.

shown that the normal human eye has more acuity for some color differences than for others. The eye seems to have greatest acuity for color differences extending roughly from orange to cyan (blue-green) as indicated by the "wide-band axis" line on the color triangle shown in Fig. 1. The I chrominance signal is so proportioned as to correspond to this line, and is transmitted with a nominal bandwidth of 1.5 mc. A second chrominance signal is chosen to correspond to the line marked "narrow-band axis," along which the eye has so little resolving power that a bandwidth of only about 0.5 mc is satisfactory. (The exact location of the Q or narrow-band axis line is established in such a way as to permit simplified receiver designs.)

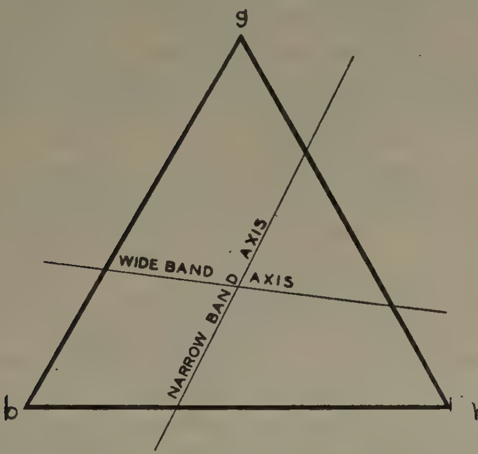


Fig. 1—Maxwell triangle for a color process showing narrow-band and wide-band axes.

The second basic operation in the RCA color television system is the multiplexing operation which permits the luminance signal and the two chrominance signals to be transmitted in a single channel. This is accomplished by modulating the two chrominance signals upon two subcarriers of the same frequency but in phase quadrature, producing a resultant subcarrier signal, variable both in amplitude and phase, which can be added directly to the luminance signal. Cross talk between the luminance and chrominance information is effectively avoided by using a subcarrier frequency (3.579545 mc) which is an odd multiple (455) of one-half of the line frequency. When the subcarrier frequency is controlled in this manner, the subcarrier automatically reverses in polarity between successive scans of each picture area, and the interference patterns corresponding to cross talk between the luminance and chrominance signals tend to cancel out through the persistence of vision.

The term "colorplexer" was coined by J. D. Spradlin, formerly of RCA Victor, to designate the equipment which performs the basic matrixing and multiplexing operations in the RCA color television system. A simplified block diagram of this equipment is shown in Fig. 2. Note that in addition to circuits for matrixing, for band-limiting the chrominance signals, and for modulating the subcarrier, there are provisions for generating color synchronizing burst and for adding standard horizontal synchronizing pulses. In the following sections of this paper, descriptions of each part of a typical colorplexer will be presented.

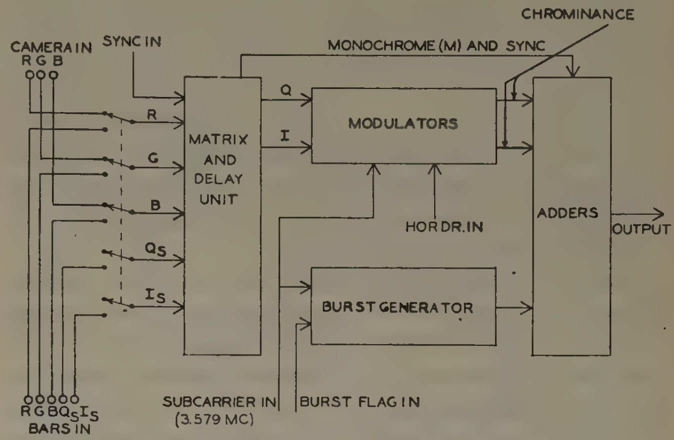


Fig. 2—Simplified block diagram of colorplexer showing principle functions.

Matrix Circuits

Previously, we have discussed the need for the matrixing, or cross-mixing, operation. Now we will see how this is accomplished. One possible arrangement would be with the use of vacuum-tube addition where the plates of three tubes are connected to a common load impedance. This has some definite practical limitations in that tubes inherently have a tendency to change gain and also may give nonlinear outputs unless extreme care is given in their circuit design. A more practical circuit is one which employs simple resistance matrixing. Fig. 3 shows a partial block-schematic diagram of the matrixing networks for producing the desired lu-

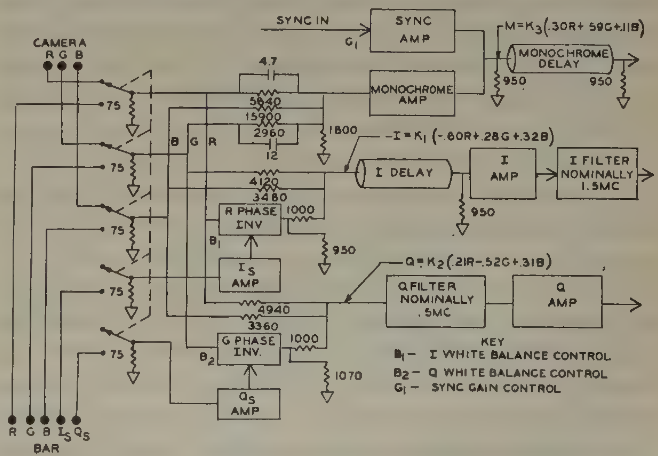


Fig. 3—Partial block-schematic diagram of matrix and delay section.

minance, or M signal, and the two color-difference signals, Q and I, as used in the colorplexer. The diagram also shows the delay and band-limiting filter circuitry which will be discussed in detail later.

The resistors of each network are so proportioned than when the proper red, green, and blue signals are applied to the input, the correct division of voltages appears at the matrix outputs, which satisfy the equations for Q, I, and M, where

$$-I = K_1(-0.59R + 0.27G + 0.32B)$$
$$Q = K_2(+0.21R - 0.52G + 0.31B)$$
$$M = K_3(\quad 0.30R + 0.59G + 0.11B).$$

K_1, K_2, and K_3 are constants of attenuation which are absorbed in the gains of later amplifier tubes. The $-I$ signal produced by this circuit is just as good as a $+I$ signal, since it is easy to correct the polarity in the modulator circuit which follows.

To keep cross talk to a minimum, the resistance path between any two inputs must be kept high with respect to the low impedance input, but it cannot be made excessively high because of the resistors' shunt capacities. The shunting effect will vary directly with the ohmic value of the matrix resistor. Therefore, the lower values of resistance in a branch must be compensated with physical capacities to match the frequency response characteristic of the largest resistor branch.

Gain controls in the grid circuit of R and G phase inverters determine the amplitude for the $-G$ and $-R$ portion of the Q and I signals; i.e., control B_2 sets the amplitude of the minus green portion in the Q signal. These controls are known as white balance controls and must be adjusted so that both Q and I cancel to zero for signals corresponding to white or neutral (where $R=G=B$).

An additional requirement of the Q and I matrices, besides determining the proper ratios and polarities of primary colors to produce proper Q and I video signals, is termination of the delay cables or networks in their proper surge impedances. In other words, the total equivalent resistance of the Q matrix must be such that it presents the proper terminating impedance of 1000 ohms to the following filter network. The same is true of the I matrix with respect to the RG-65/U cable used to delay the I video information.

If the matrix is correct, the input signals are correct, and the white balance controls are adjusted properly, then the signals emanating from the matrix section will convey true Q, I, and M video information.

Provision is made at the colorplexer input for selecting either camera signals or color bar test signals for transmission through the unit. When the selector switch is in the "color bar" position, there are two more inputs in addition to the red, green, and blue video inputs. These inputs are for special test pulses, Q_s and I_s, which are supplied by the color-bar generator and which are inserted directly into the Q and I channels to facilitate phase adjustments of the doubly-balanced modulators. Use of the color-bar signals (including the special test pulses) for checking the colorplexer will be discussed in a later section of this paper.

Filters and Delay Lines

In the portion of the colorplexer shown in Fig. 3 are the filters which determine the frequency response characteristics for the Q and I channels, and also the delay lines which are necessary to keep the signal components in time coincidence at the colorplexer output. Let us now consider the design factors affecting these filters and delay lines.

The delay of a filter or of a transmission line refers to the time required for a signal to traverse the filter or line in one direction. One of the requirements for faithful transmission of signals is that the delay be constant for all of the significant frequency components of the signal.

When low-pass filters are used for band-limiting, as is necessary for the Q and I channels, the delay, T, per section, approaching zero frequency, is inversely proportional to the design cutoff frequency, f_c, as follows:

$$T = \frac{\sqrt{\dfrac{1+2K}{1-2K}}}{\pi f_c} \quad \text{for "}\pi\text{" sections, and}$$

$$T = \frac{\sqrt{\dfrac{1+K}{1-K}}}{\pi f_c} \quad \text{for "}T\text{" sections.}$$

The letter "K" denotes the coefficient of mutual coupling between whole sections for the "π" and half sections for the "T." The numerators in the above equations are equal to the derived "m" factors introduced by Zobel[1] to provide for mutual coupling in the prototype equations.

Mutual inductive coupling by itself, and sometimes assisted by bridging capacitive coupling, is used to make the delay more constant through the frequency passband. Pierce[2] may have been first to use mutual inductive coupling for this purpose. Largely because of smaller space, mutually-coupled π sections are more attractive for long lines than T sections which usually have all of the coupling within the section rather than between sections. The literature contains several references to bridged-π filters and delay lines which are delay-compensated almost to the cutoff frequency. Batchelder,[3] Golay,[4] and Hopper[5] are among others. Hebb, Horton, and Jones[6] and Turner[7] have given similar prescriptions for bridged-T lines which are also delay-compensated nearly to the cutoff frequency.

[1] O. J. Zobel, U. S. Patent 1,538,964.
[2] G. W. Pierce, U. S. Patent 1,576,459.
[3] L. Batchelder, U. S. Patent 2,250,461.
[4] M. J. E. Golay, "The ideal low-pass filter in the form of dispersionless lag line," Proc. I.R.E., pp. 138P–144P; March, 1946.
[5] A. L. Hopper, "Non-synchronous pulse transmission," *Electronics*, pp. 116–120; August, 1952.
[6] Hebb, Horton, and Jones, "On the design of networks for constant delay," *Jour. Appl. Phys.*, pp. 616–620; June, 1949.
[7] A. H. Turner, "Artificial lines for video distribution and delay," *RCA Rev.*, pp. 477–489; December, 1949.

In general, these authors select a certain value of derived "m" of approximately 1.46 when the mutual inductive coupling is assisted by capacitative bridging coupling, and a value of approximately 1.28 when inductive coupling is used alone. These are related to the coefficients of coupling as:

$$K = \frac{m^2 - 1}{2(m^2 + 1)} \text{ for } \pi \text{ sections}$$

$$K = \frac{m^2 - 1}{m^2 + 1} \text{ for } T \text{ sections.}$$

These equations give preferred coupling coefficients of 0.18 and 0.12 between π sections and 0.36 and 0.24 between halves of T sections, corresponding to "m" values of 1.46 and 1.28.

Let us consider the filter used for the Q channel first because it has the lower cutoff frequency and therefore the greater delay. The NTSC recommendations regarding the attenuation of the Q filter are quite broad. The proposed signal specifications state that the Q filter should be less than 2 db down at 400 kc, less than 6 db down at 500 kc, and at least 6 db down at 600 kc. The slow rolloff of one section or the steep cutoff of a dozen sections would fit within these tolerances, but every filter section added here increases the Q filter delay and also increases the amount of delay which must be added to the I, M, and sync channels to match the delay of the Q signal. (Note that the NTSC signal specifications state that components of Q, I, and M must match each other in time to 0.05 μsec.)

For this reason, the RCA colorplexer uses for the Q channel filter a single section of T with aiding mutual coupling. Fredendal of RCA Princeton Laboratories suggested the addition of wing traps to the T to improve the amplitude symmetry of the cutoff and the constancy of the delay through the cutoff. In both of these properties, the filter is excellent, but with a cutoff slope of this magnitude in a single filter section, we must inherently have noticeable ringing at the cutoff frequency. The overshoot of the first ringing cycle is between 5 and 10 per cent. Fortunately, the eye is seldom able to perceive the ringing, since it occurs only for color difference information for which the eye has low acuity. The delay of this filter remains very constant at 1.4 μsec to 575 kc where the amplitude has fallen 6 db.

The NTSC signal specifications again are quite broad for the I channel bandwidth. According to the proposed signal specifications, the response should be less than 2 db down at 1.3 mc and at least 20 db down at 3.6 mc. Fast or slow attenuations will fit between the two widely-spaced reference points. However, we believe that the advantages of a slow rolloff providing constant delay and negligible overshoot more than offset the disadvantages of some loss in chrominance resolution. Therefore, the amplitude response of the I channel in the RCA colorplexer is just comfortably within the NTSC specifications. The slow rolloff is obtained from a modified Dietzold[8] network. The delay of this network is approximately 0.2 μsec, requiring an additional 1.2 μsec of delay to match that of the Q channel. Thirty feet of RG-65/U delay cable provide this delay. To compensate for the amplitude attenuation-versus-frequency of the cable, cathode peaking is used. The phase-advancing effect of cathode peaking also tends to cancel the phase-retarding effect caused by the properties of the RG-65/U cable.

The bandwidth of the monochrome channel is at least 8 mc all the way through the colorplexer. While no restrictive filter is used in this channel, delay compensation is required. A constant delay up to and slightly beyond 5 mc is needed. Thirty-five feet of RG-65/U delay cable provides a constant delay of 1.4 μsec with adequate frequency response for delaying the monochrome information.

As shown on the block diagram of Fig. 3, sync is added to the M signal ahead of the M delay, thus eliminating the need for a separate delay line for sync in the colorplexer. However, if a studio arrangement is such that sync is inserted at some point in the system beyond the colorplexer, such as at the output of a switching system, then an additional delay unit is required for sync.

I and Q Modulators

It was noted in the introduction to this paper that the I and Q chrominance signals are prepared for transmission by modulating them upon two subcarriers of the same frequency (approximately 3.6 mc), but in phase quadrature. Suppressed carrier modulation is used, so that the subcarrier signal goes to zero when both I and Q are zero (as for neutral colors). Since I and Q may be either positive or negative, each subcarrier component may be either positive or negative (a suppressed-carrier signal suffers a polarity reversal each time the modulating signal passes through zero). The resultant subcarrier signal produced by adding the two quadrature components may therefore have any phase within the full 360-degree phase circle.

The modulators used for the I and Q signals are of the doubly-balanced type[9,10] shown in block diagram form in Fig. 4. In this circuit, a pair of pentode modulators is used with a common output, but with push-pull inputs for both the video signal and the carrier signal. If the circuit is properly balanced, both the original video signal and the carrier signal cancel at the output, leaving only the product signal, which is the desired modulated wave. A simplified schematic for a doubly-balanced modulator is shown in Fig. 5. The legend or key used on the block diagram of Fig. 4 also applies to the partial schematic in Fig. 5.

[8] "Dietzold Network," M.I.T. Radiation Laboratory Series, McGraw-Hill Book Co., Inc., New York, N. Y., vol. 18, p. 67.

[9] Petersen and Keith, "Grid-current modulation," *Bell Sys. Tech. Jour.*, vol. 7, p. 131; 1928.

[10] "Balanced Modulators," M.I.T. Radiation Laboratory Series, McGraw-Hill Book Co., Inc., New York, N. Y., vol. 19, p. 416.

The pentode modulator tube type used in the RCA colorplexer is the 6AS6. It is especially suited to this application for these reasons:

1. Number one grid, used for video, has a reasonably linear control of plate current.
2. Number three grid, used for subcarrier, has a higher than usual transconductance to the plate.
3. The tube is of miniature size with 7-pin base.

Although the plate of the 6AS6 is not shielded from the number three grid, the capacitance between them is small, and the subcarriers leaking through each modulator pair by these paths cancel each other, being of equal amplitude and of opposite phase.

In common with most multigrid tubes, the 6AS6 has a hump in the transconductance characteristic of number three grid to plate, with its peak at approximately 5 volts negative with respect to the cathode. If the subcarrier applied to this grid is held at constant amplitude, this slope will not produce a disturbing rectified output.

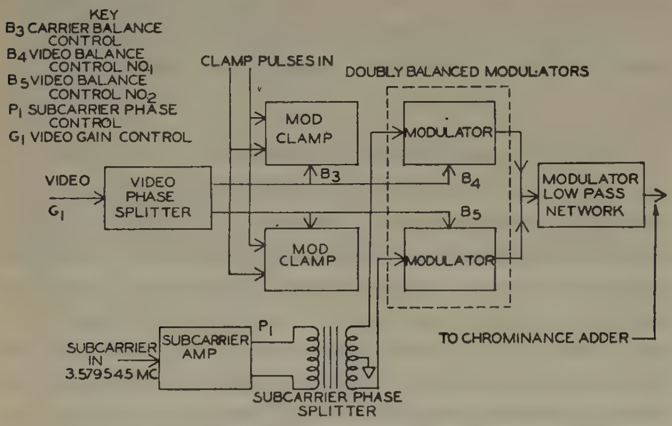


Fig. 4—Block diagram of a doubly-balanced modulator section.

It should be pointed out that a modulator of the type used here is a multiplying device producing an output proportional to the product of the voltages on the two control grids. No curvature of the grid voltage-plate current characteristics is either necessary or desirable for this action.

Video signals of opposite polarity for each modulator are obtained from one-half of an RCA type 12AU7 triode "phase-splitter." This term is applied to a tube providing two outputs from equal cathode and plate load resistors. This circuit must be used with care at high frequencies because of the great difference of the internal resistances of the cathode and plate. The video swing to each modulator grid is less than 0.5 volt, peak-to-peak, to insure good modulator linearity. A conventional gated clamp is used to restore the dc component of the video signal on each modulator grid.

The oppositely-phased subcarriers for each pair of modulators are obtained from a well-balanced tuned transformer. Here we are limited in voltage swing only by excessive harmonic production. This limit depends upon the tube matching, but is approximately 3 volts (peak-to-peak) of carrier on the grids. Modulator phase adjustment is made by control P_1 in the transformer primary circuit.

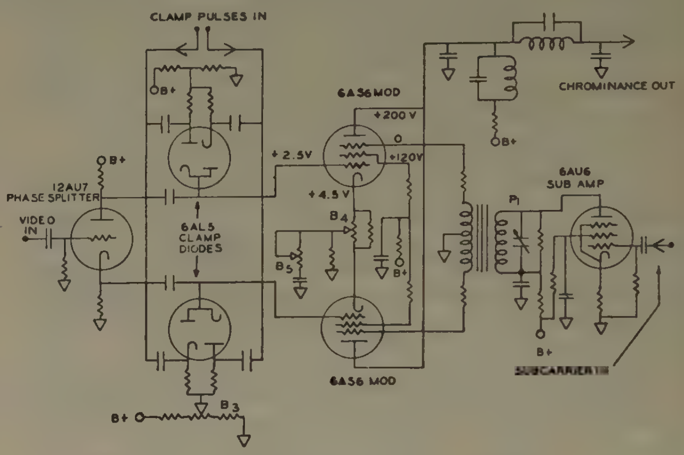


Fig. 5—Partial schematic showing doubly-balanced modulator section.

As shown in the schematic of Fig. 5, three modulator balancing controls are used with each pair. The positive bias control for one clamp is labeled "carrier balance," and its function is to balance the tube electron streams so that both tubes will have equal transconductances from number three grids to plates. It is also necessary to balance the number one grid transconductances for video cancellation. This is more complicated and involves both the differential gain potentiometer marked "video balance No. 1" and the cathode ac impedance potentiometer marked "video balance No. 2." It should be noted that the common cathode circuit is not bypassed for video, permitting each modulator to drive the other through this cathode circuit. If the tubes are well matched, the video voltage at the common plates is cancelled by the "No. 1" control at the same time that the video is cancelled at the common cathode impedance. If the tubes are not matched, the video can be cancelled at the common plate circuit by unbalancing the cathode video voltages slightly by the "No. 1" control while varying the cross-driving impedance in the cathode by the "No. 2" control. These video balancing controls seldom need changing unless the modulator tubes are replaced.

The widest, useful frequency band from the modulators extends from 2 to 5 mc, which includes the subcarrier sidebands of the I channel. Reasonably well-matched tubes will produce very little of the unwanted video frequencies and very little of the carrier and video harmonic frequencies. A low-pass filter is used in the common output line to suppress harmonics of the subcarrier which may be produced under some conditions.

It should be understood that two identical doubly-balanced modulators are used in the colorplexer—one for I and one for Q. A delay network is used to establish the 90-degree relationship between the subcarrier inputs to the two channels.

Burst Generator

The two-phase modulation technique, which is used in the RCA color television system, requires that special synchronizing information be transmitted to provide for the locking in of receivers to the exact frequency and phase of the system subcarrier frequency generator. This synchronizing information is provided in the form of 8 cycles of subcarrier at a particular phase relative to the chrominance information and transmitted after each horizontal sync pulse.

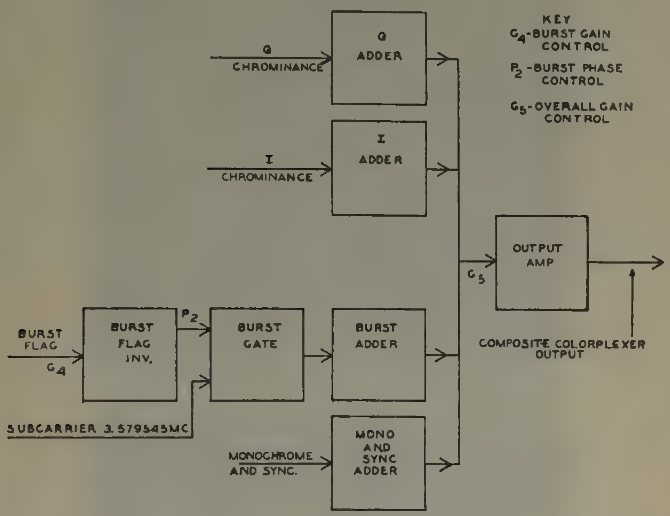


Fig. 6—Block diagram of adders, output, and burst generator sections.

The burst signal is provided by circuitry, as shown in Fig. 6. A burst-flag pulse, appearing in time immediately following the horizontal sync, is used to key on a 6AS6 gate tube. A band-pass filter in the gate tube output eliminates the low-frequency and second harmonic information, leaving a burst of subcarrier information. A phase control, P_2, is provided for adjustment of proper burst phase. Gain control, G_4, establishes the desired amplitude for the burst signal.

Adders and Output Stages

The modulated subcarrier signals from the Q and I doubly-balanced modulators must now be combined, not only with each other, but also with the monochrome signal and the necessary synchronizing information. (The synchronizing information includes horizontal sync and the color burst.)

The term adder is used instead of mixer to denote strict linear addition of the chrominance, luminance, and synchronizing information. The adder circuits are simple pentode amplifier stages with their plates tied together to a common load impedance which has sufficient bandwidth to pass all the chrominance and luminance information. The isolating effect of pentodes is used to good advantage in the adder circuits to prevent interaction between the signals fed to the various adder grids. The gains of the four adder stages are controlled and fixed by the degenerative, unbypassed resistors in the separate cathode circuits. The common load impedance for the adders consists of a low-pass network of the type previously referred to as the modified Dietzold. This network is essentially flat to 8 mc, and has a slow rolloff with constant time delay out to the 6-db point.

The output section of the colorplexer consists of two feedback pairs. The first section provides the necessary voltage gain to drive the second section which has been designed as a unity gain device with three separate and isolated outputs to drive three 75-ohm coaxial lines. A low impedance over-all gain control is provided between the two feedback pair sections.

Layout and Shielding

Because of the nature of the signals being used in the colorplexer, considerable emphasis must be placed on proper layout of components, plus shielding and isolation of signal paths. The components in the RCA colorplexer have been arranged so as to provide a straight, direct path from input to output with a minimum of interference between different signal paths, both physically and electrically. In Fig. 7, showing a rear view of the complete colorplexer chassis, one can see how the circuitry has been arranged. The signal progression is generally upward in the chassis being discussed. This prevents the output tubes, which have higher plate dissipations, from affecting some of the more critical circuits, which are critical to temperature. Lead lengths

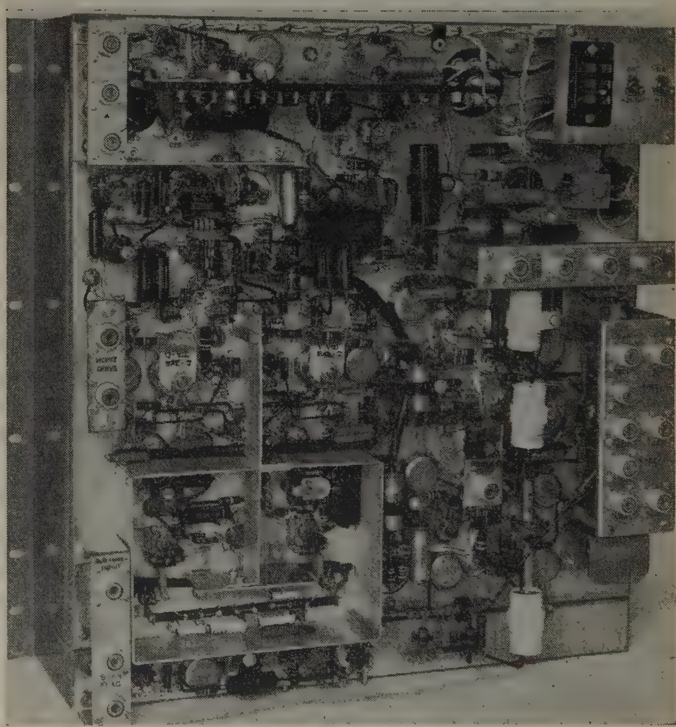


Fig. 7—Rear view of colorplexer chassis. (I and M delay cables not shown.)

are made as short as possible. Special emphasis has been given to the orientation of tube sockets to prevent input and output leads from crossing or paralleling.

To reduce the tendency for cross talk between quadrature phases of subcarrier, special shielded areas have been provided. An idea of the importance of keeping spurious quadrature cross talk to an absolute minimum can be shown best by an example. 1.75 per cent of Q subcarrier cross talk in the I channel would produce an error of 1 degree in I phase.

Discussion of Wave Forms

It would be helpful at this point to discuss the operation of the colorplexer by considering some of the wave forms produced at different points in the circuit, using an RCA color-bar generator as a video signal source. The color-bar generator is essentially a group of multivibrators connected in such a manner as to produce noise-free video pulses in the three primary channels corresponding to a color-bar pattern like that shown in Fig. 8. (The color-bar generator also produces special test pulses which may be inserted at appropriate points in the system as indicated in Fig. 3.) With the key or guide included in Fig. 8, it is a simple matter to interpret the color-bar pattern in terms of the three primary video signals. For example, the yellow portion of the pattern is composed of a mixture of red and green. To avoid confusion, the white of the color-bar pattern is not cross-hatched, but it should be understood, however, that white is actually a mixture of all three primary colors, red, yelow and blue.

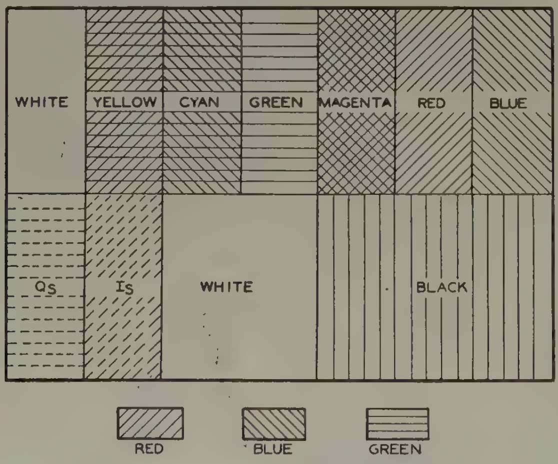


Fig. 8—A kinescope view of a typical color-bar pattern.

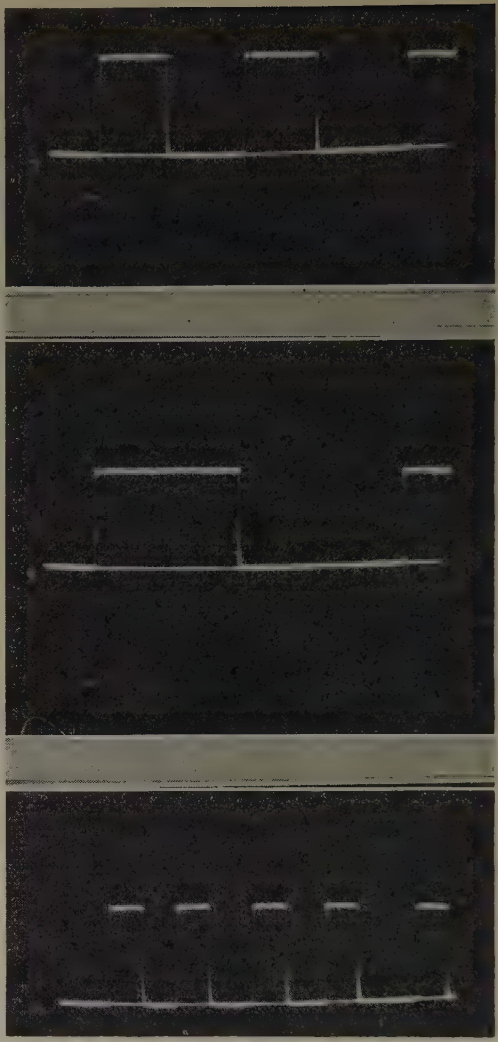


Fig. 9—Wave forms of red, green, and blue outputs of color-bar generator.

The red, green, and blue waveforms which correspond to the bar pattern appearing in Fig. 8 are shown in Fig. 9.

The signals appearing at the output of the matrix and filter section are shown in Fig. 10. The luminance or monochrome signal is shown in Fig. 10(c). Note that the colors in the particular pattern being discussed are arranged in descending order of luminance. It is this M or luminance signal which makes it possible to view a color television picture in black-and-white on present monochrome receivers. Figs 10(a) and 10(b) show the Q. and I signals, respectively. One striking feature of these wave forms is that they have both negative and positive values (the M signal never goes negative). Note that each complementary color produces a signal voltage equal, but opposite in polarity to one of the primaries in both the Q and I channels. That is, the signal for yellow is minus blue; purple or magenta is equal to minus green; and cyan is equal to minus red. Inspection of the Q and I wave forms reveals interesting differences between the pass bands of the two circuits. Note that the I signal has more rapid transitions than the Q signal because its channel has roughly three times the bandwidth. The ringing in the Q signal is caused by the sharp cutoff of the Q filter. As noted earlier, this ringing is not visible in the final color picture.

When the Q and I signals are modulated upon subcarriers in the doubly-balanced modulators, they produce the wave forms shown in Figs. 11(a) and 11(b). Note that the subcarrier envelope follows the original

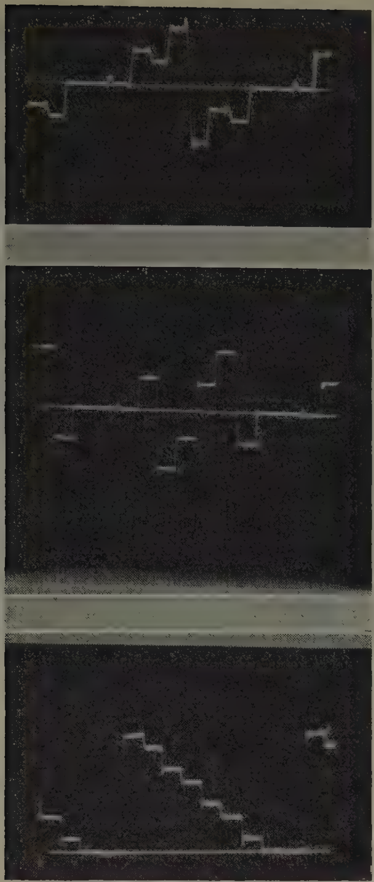


Fig. 10—(a) Wave form of Q video information from Q matrix and delay section. (b) Waveform of I video information from I matrix and delay section. (c) Waveform of monochrome information from M matrix.

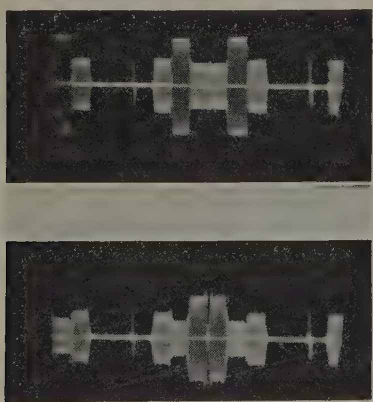


Fig. 11—(a) Wave form of I chrominance information. (b) Waveform of Q chrominance information.

wave forms except that the polarity reversals appear only as a reversal of subcarrier phase. These two signals are combined, in quadrature, to produce the complete subcarrier signal shown in Fig. 12; this signal varies both in amplitude and in phase from one color to another.

As indicated in Fig. 8, the actual color-bar pattern is supplied by the bar generator for only half of each vertical period. During the remaining time, special test pulses are transmitted. Two of these pulses, Q_s and I_s, are injected into the Q and I channels, respectively, by the means shown in Fig. 3, to produce the two wide bursts shown in Fig. 13 (which is the horizontal wave form corresponding to the bottom half of the bar pattern). These bursts permit measurements of the phase adjustments of the Q and I channels while the colorplexer is in normal operating condition. The third test pulse is a white pulse, which is added in equal amounts to the red, green, and blue channels. This white is adjustable in amplitude (in the color-bar generator) relative to the other white bar which appears in the top half of the pattern. Sync and the color synchronizing burst are also shown in Fig. 13.

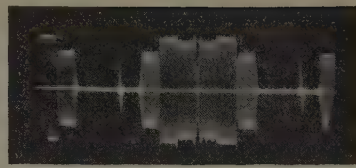


Fig. 12—Wave form of Q and I chrominance information combined.

Fig. 13—Wave form of Q_s, I_s, special chrominance signals and independent white bar.

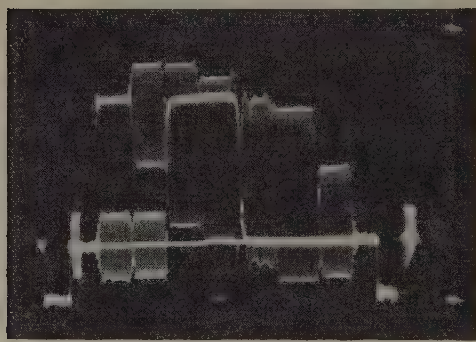


Fig. 14—Wave form of complete colorplexed signal using color-bar video source.

The complete bar-pattern test signal produced by the colorplexer is the summation of Figs. 10(c), 12, and 13, and appears as shown in Fig. 14. Note that the color subcarrier "overshoots" the black-to-white monochrome signal range by 33 per cent in both directions. The bar pattern is so arranged that the wave form can be viewed without interference between the special Q_s and I_s test bursts and the actual color bar signal.

Physical Characteristics

Fig. 15 is a front view photograph of the colorplexer, showing the arrangement of the major components. The colorplexer is built on a standard bathtub chassis, $19\frac{3}{4}$ inches high. A 117-v ac input is required for the filaments and bias supply. A plate source of 280-v dc at 380 ma is also necessary. Most of the 34 tubes used are pentodes which provide a higher degree of circuit isolation.

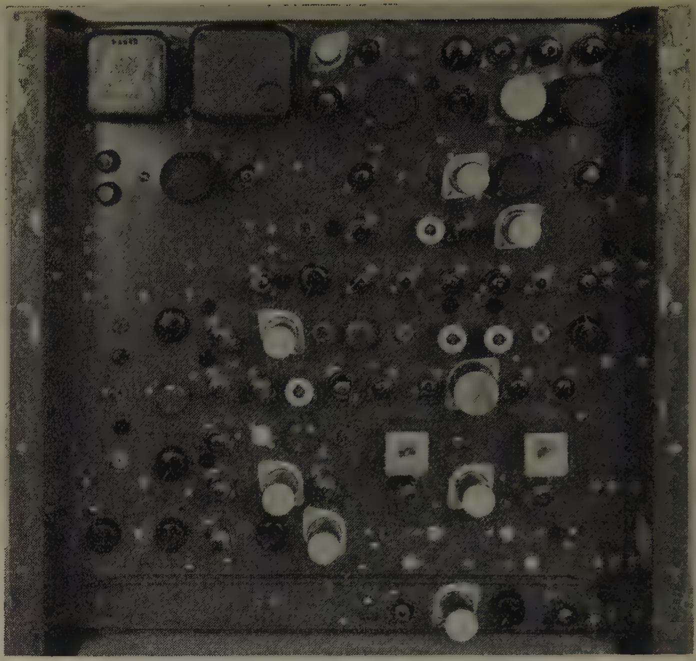


Fig. 15—Front view of colorplexer chassis.

Conclusion

Colorplexers of the design discussed in this paper have been installed at NBC's Colonial Theater color studios in New York City where they have shown good performance under actual operating conditions.

Acknowledgment

The writers wish to express their appreciation to John W. Wentworth for his capable assistance and direction in the preparation of this paper.

Transients in Color Television*

P. W. HOWELLS†, MEMBER, IRE

Summary—**A color television system transmits three independent signals, each of which specifies one of the three co-ordinates that determine the location of the reproduced color in a three-dimensional color space. When a color transient occurs, each of these signals responds in a different manner determined by the characteristics of its own channel. The system response may be characterized by the resulting path along which the reproduced color point moves through the color space from its initial to its final location. The shape of such color transient paths as determined by the individual transient responses of the three channels is analyzed, and the subjective appearance of different transient-path shapes is discussed.**

Introduction

THE main difference between monochrome and color television lies in the amount of information needed to specify an element of the picture being transmitted. In monochrome transmissions the picture element is completely specified when we know its luminance. In color transmissions the picture element is completely specified when we know three quantities, such as the amounts of three primary lights required to match its color. Thus, we may say that in monochrome television the information transmitted is the location of each picture element on a one-dimensional luminance scale while in color the information transmitted is the location of each picture element in a three-dimensional color space.

The operation of the color system might be described as follows: the camera, in scanning the scene, makes a colorimetric analysis of the picture element under scan and produces three output voltages. Let us say that the camera is so designed that these three voltages represent the amounts of the NTSC display primaries, (R), (G), and (B). These voltages determine a point in color space, the camera color point. In the process of coding the color signals for transmission, the R, G, B voltages undergo a linear transformation (9), (Appendix I) which produces three related voltages representing the amounts of the NTSC transmission primaries (W), (I), and (Q). (Let us ignore gamma precorrection for the time being.) These transmission primary voltages still determine the location of the camera color point, but in terms of a different set of cartesian axes in the color space. Between the point at which they are formed and where they are recovered in the receiver, the transmission primary signals undergo the usual difficulties

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with noise and interference, and the different bandwidth limitations necessary for simultaneous transmission through the 6-mc channel.

At the receiver, an inverse transformation is performed on the transmission primary voltages to regain the display primary voltages R, G, B for application to the tricolor display. The transmission primary signals (or the R, G, B signals) at the receiver determine the location of the receiver color point in color space. For perfect reproduction, this receiver color point should coincide with the camera color point. In practice, the system should be so designed that the colorimetric deviations of the receiver color point from the camera color point due to noise, interference, and band limiting are such as to produce the least perceptible effect in the picture.

The Color Transient

As the color camera scans the scene, the scanning aperture encounters areas of different color, and the camera color point responds by moving about through the color space. As long as its motions are not too rapid, the receiver color point is able to follow them exactly. However, when the scanning aperture crosses a boundary between areas of different color, the camera color point may change position too rapidly for the receiver color point to follow. Since the transmission primary signals have different bandwidths, the path taken by the receiver color point in response to this shock is a complex one. Being able to move more rapidly in some directions than in others through the color space, it traces out a curving path having several more or less abrupt changes in direction. This three-dimensional path through color space, plotted as a function of time, may be called the transient response of the color system. It is analogous to the curve of luminance versus time which represents the over-all transient response of a monochrome system and, in a similar way, its shape affects the appearance of transitions in the color picture.

Given the transient responses of the individual signal channels, it is the purpose of this paper to develop means of determining the color transient response of the system. Such a four-dimensional figure is difficult to display as a whole, so it will be analyzed into its component luminance and chromaticity transients.

The Color Space[1,2]

For a study of the transient response of the color system, it is most convenient to deal with a color space whose axes correspond to the three transmitted color signals E_W, E_I, and E_Q, since it is these signals which are band limited in the process of transmission. If gamma is assumed to be unity, it can be shown[3] that these signals represent the amounts of three primaries known as the transmission primaries, (W), (I), and (Q). Fig. 1 shows such a linear color space. The vertical axis in this sketch corresponds to the NTSC luminance primary (W), which has the chromaticity of Illuminant C white and which supplies all of the luminance of the color produced by the receiver. The two horizontal axes correspond to two chrominance primaries. These are nonphysical zero-luminance primaries similar to the (X) and (Z) primaries of the CIE system of color specification. The base plane of Fig. 1 is therefore a plane of zero luminance, and higher horizontal planes are planes of constant luminance. If equal units on the two chrominance primary axes are made to represent an equal number of volts of the corresponding signals transmitted in quadrature on the color subcarrier, the base plane may also be considered as a phasor diagram of the color subcarrier, in which the amplitude and phase of the color subcarrier may be measured directly.

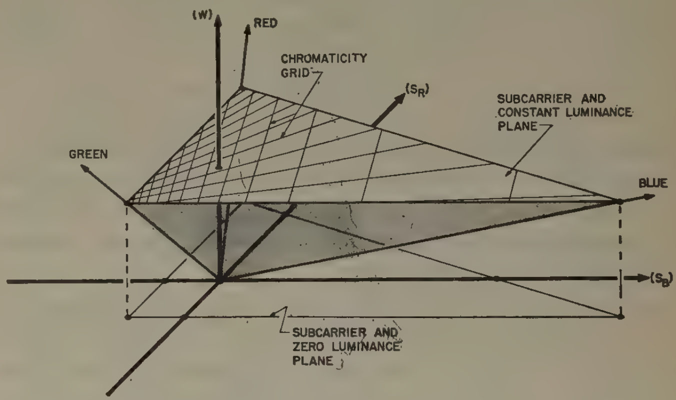

Fig. 1—Color space in terms of transmission primaries.

It is somewhat simpler to construct this color space in terms of the earlier chrominance primaries $(R-W)$ and $(B-W)$, than (I) and (Q). [Equations (11–14), Appendix I.] The (I) and (Q) axes are then located 33 degrees counterclockwise from the $(R-W)$ and $(B-W)$ axes, respectively. The units of equal size on the $(R-W)$ and $(B-W)$ axes

$$S_R = \frac{R - W}{1.14},$$

and

$$S_B = \frac{B - W}{2.03},$$

corresponding to the weight given these signals in transmission.

As with other sets of primaries, the chromaticity of a color is determined by the ratio of the amounts of the primaries required to match it. This means that all lights having the same chromaticity lie on a straight line which pierces the origin. The Illuminant C line, for example, is the vertical (W) axis, while the NTSC primary (R, G, B) axes are oriented as shown in Fig. 1.

[1] W. T. Wintringham, "Color television and colorimetry" Proc. I.R.E., vol. 39, pp. 1135–1172; October, 1951.

[2] F. J. Bingley, "Colorimetry in Color Television," Proc. I.R.E., pp. 51–57, this issue.

[3] P. W. Howells, "The concept of transmission primaries in color television," Proc. I.R.E., pp. 134–138, this issue.

A constant luminance plane is shown in the sketch; the boundary of the plane is the RGB color triangle determined by these axes. We may transfer the chromaticity diagram to this plane, [(21) and (22), Appendix III]. For this case, where gamma is unity, the lines of constant x transform to the set of lines radiating from a point beyond the green primary, while the lines of constant y become the set of parallel lines shown.

The Effects of Gamma Precorrection

In the preceding discussion, the assumption has been made that the electrical signals are linearly related to the colorimetric quantities they represent. In a practical system, this is not the case. The color display device has an approximately exponential transfer characteristic with an exponent of γ. The correct primary signals for this tube, then, are not R, G, and B, but

$$R' = R^{1/\gamma},$$

$$G' = G^{1/\gamma},$$

and

$$B' = B^{1/\gamma}.$$

(Note: Expressions involving electrical or colorimetric quantities in nonlinear relationships may not be dimensionally correct unless supplied with the proper conversion factors. These conversion factors are omitted in the interest of brevity.)

Precorrection of the R, G, and B primary signals for the nonlinear characteristics of the cathode-ray tube is performed at the transmitter. Subsequent linear operations to convert these gamma corrected signals to the transmission signals and, at the receiver, to convert them back, are performed exactly the same as in the linear case. Where the transmission primary signals are formed in this way from gamma corrected primary signals, they are primed to indicate this fact.

Because of this nonlinear relation between colorimetric quantities and electrical signals, the picture of Fig. 1 must be somewhat revised. The transmission signals now establish a curvilinear co-ordinate system for the color space. Alternatively, if we represent colorimetric quantities in terms of linear cartesian axes corresponding to the gamma-corrected transmission signals, W', I', Q', (or W', S_R', S_B'), the chromaticity diagram and the constant luminance surfaces are warped from their original shapes.

Fig. 2 shows such a space. As far as the electrical quantities are concerned, the space is identical to that of Fig. 1. The base plane still corresponds to the phasor diagram of the color subcarrier. It can be shown [(21) and (22), Appendix III], that a given ratio of the gamma corrected transmission signals still corresponds to a particular chromaticity, so straight lines from the origin still locate all lights of the same chromaticity. However, in general, the direction of the line is different than in the linear case of Fig. 1. Exceptions to this rule are the NTSC display primaries, their complements and Illuminant C. For these special cases, the ratios of the R, G, B signals after gamma correction are the same as before, so these axes are located exactly as in the linear case.

The Effect of the Subcarrier on Luminance

Fig. 2 shows a subcarrier plane (or plane of constant W'), bounded by the NTSC color triangle. This plane is no longer a surface of constant luminance. For a gamma of 2, these surfaces, as defined by (15), Appendix II, are a family of similar, concentric ellipsoids. The curved surface shown is the section of one of these constant luminance surfaces bounded by the NTSC color triangle. Note that this surface is parallel to the subcarrier surface at the (W') axis, that is, the subcarrier plane approximates a constant luminance surface very well near Illuminant C, but less and less closely as the saturation increases. The contours defining the constant luminance surface are its intersections with various subcarrier planes. Similarly the contours shown on the subcarrier plane are its intersections with the constant luminance surface shown, and several surfaces of higher luminance.

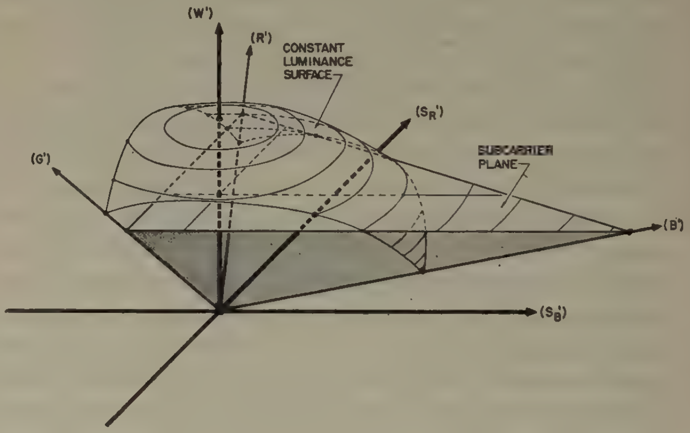

Fig. 2—Color space with gamma correction.

The effect of the subcarrier on luminance may be shown by a map of these intersections in the subcarrier plane, Fig. 3. The origin of the subcarrier plane (at Illuminant C) marks its point of tangency with a particular luminance surface, and the contours indicate its intersections with surfaces of higher luminance. The luminance factor, K_S, on each contour is the ratio of the luminance on the contour to that at Illuminant C. As indicated by (16), Appendix II, the luminance factor depends only on the ratio of the transmission signals, so a normalized diagram, good for all levels of the luminance (W') signal, may be constructed in terms of the ratios S_R'/W' and S_B'/W'. The factor K_S indicates the contribution of the subcarrier to the luminance of the receiver color point according to the equation

$$Y = K_S W'^{\gamma}, \quad [(16a), \text{Appendix II}]$$

where W'^{γ} is the luminance which will be produced by

luminance signal alone. For example, where $K_S=2$ the "luminance" signal contributes only one-half of the total luminance, while the color subcarrier contributes the remainder. Strictly speaking, then, we should not refer to W' as the luminance signal, but as the monochrome signal.

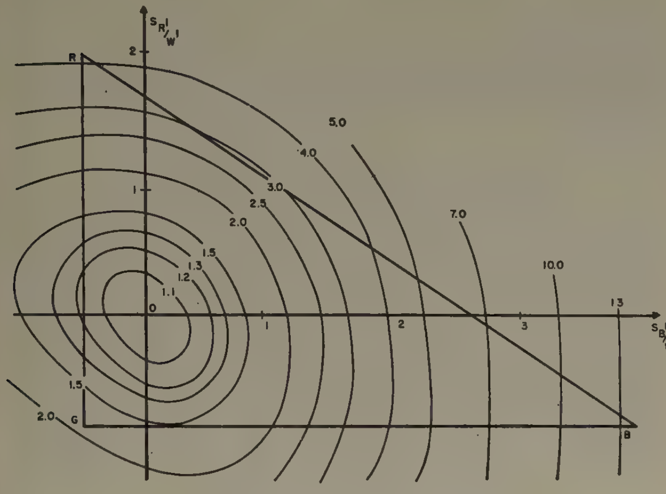

Fig. 3—Luminance factor (K_S) contours in normalized subcarrier plane, $\gamma=2.2$.

The luminance factor, K_S, is the inverse of the chromaticity factor, K_C, introduced by Applebaum.[4] Since K_S is shown in terms of the transmission signals, while K_C was evaluated in the chromaticity diagram, the derivation of the expression used to evaluated K_S is given in Appendix II.

The Effect of the Subcarrier on Chromaticity

Fig. 4 shows how the chromaticity grid appears in a normalized plot of the subcarrier plane. Gamma correction has warped the grid so that the lines of constant x and constant y are no longer straight as they were in the linear case illustrated by Fig. 1. In general, variations of the S_R' and S_B' signals have a greater effect on chromaticity (gamma times as great) near the Illuminant C point than they did in the linear case, and less effect on chromaticity near the edges of the color triangle. In these areas, much of the effect of the subcarrier goes into changing luminance rather than chromaticity.

The expressions relating S_R'/W' and S_B'/W' to chromaticity are derived in Appendix III.

Subcarrier Transients[5,6]

An important part of the over-all transient response of the color system is the transient response of the color subcarrier itself. In its recent work on color television, the NTSC has investigated two different methods of transmitting the color subcarrier, which result in radically different types of transient response:

(1) Prior to the end of 1952, both components of the chrominance signal were transmitted in a vestigial sideband fashion with the result that the quadrature component of the S_B' signal was detected in the S_R' channel, and vice versa. The feature of Color Phase Alternation (CPA) was incorporated in the system in an effort to cancel the effects of this cross talk.

(2) In the final NTSC signal specification the chrominance component requiring the least resolution for good subjective equality of the image is restricted in bandwidth so that it may be transmitted as a double-sideband signal. Quadrature components detected with both chrominance component signals may be eliminated by this scheme, since both signals are double-sideband over the frequency band they share.[7] (This system has been called the acuity-matching system, since the bandwidths of the three transmission signals are so proportioned as to match the acuity of the eye.)

The color transient response of both of these systems will be analyzed.

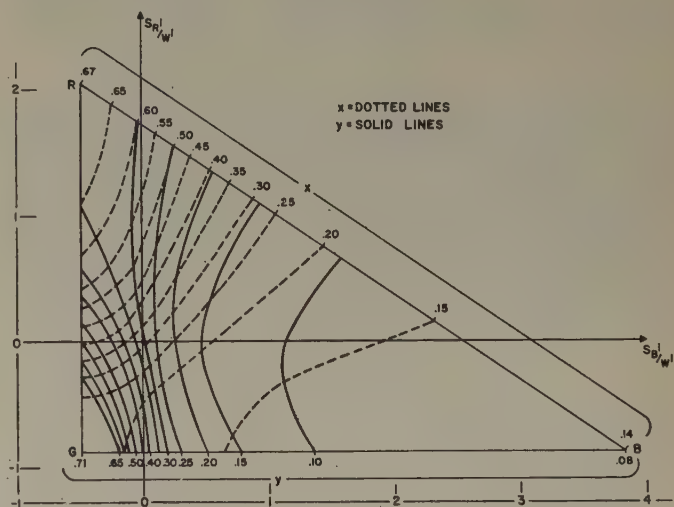

Fig. 4—Chromaticity grid in normalized subcarrier plane, $\gamma=2.2$.

Subcarrier Transient Path—Case 1

Let us assume that at a color transient the camera color point changes its position in the subcarrier (S_R', S_B') plane, moving H units along a line making the angle θ with the S_B' axis. This change in position is so rapid that for the subcarrier channel it amounts to a perfect step input. The center of the step is located at point (C_R, C_B). A sketch of this transient is shown in Fig. 5(a). The signals applied to the S_R' and S_B' channels are the components of this step resolved along the S_R' and S_B' axes, i.e., $H \sin\theta$ and $H \cos\theta$. As has been

[4] S. Applebaum, "Gamma correction in constant luminance color television systems," Proc. I.R.E., vol. 40, pp. 1185–1195; October, 1952.

[5] J. S. S. Kerr, "Transient response in a color carrier channel with vestigial side band transmission," I.R.E. Convention Record, part 4, pp. 18–23; 1953.

[6] W. F. Bailey and C. J. Hirsch, "Quadrature Crosstalk in NTSC Color Television," Proc. I.R.E., pp. 84–90, this issue.

[7] J. S. S. Kerr and P. W. Howells, "A Proposal for a Modification of the Chrominance Signal Specification," NTSC Report No. NTSC-P13-289; August, 1952.

shown by Kerr,[5] these signals are detected at the receiver as though they had been passed through the network shown in Fig. 5(b). Since the two channels are identical in this case, we may call $F_i(t)$ the in-phase unit step response of either channel and $F_q(t)$ the quadrature unit step response. The two signals detected at the receiver are therefore:

$$S_R' = C_R + H \sin \theta F_i(t) + H \cos \theta F_q(t) \quad (1)$$

$$S_B' = C_B + H \cos \theta F_i(t) - H \sin \theta F_q(t). \quad (2)$$

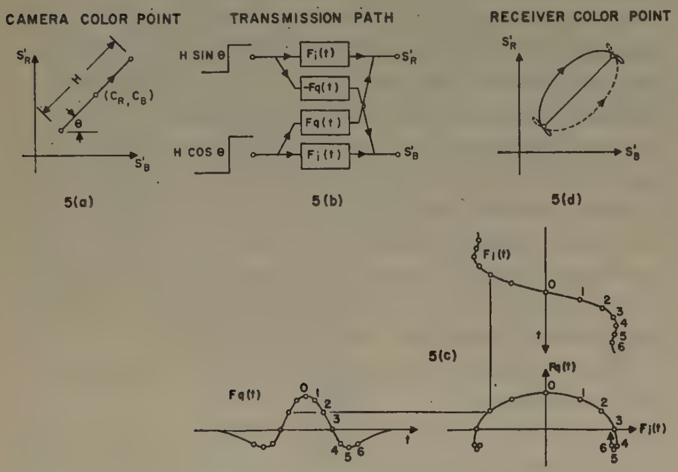

Fig. 5—Subcarrier transient path: Case 1.

Equations (1) and (2) are the parametric equations for the transient path of the receiver color point in the subcarrier plane. These equations are simplified if we translate the axes to the center of the transient and then rotate them θ degrees to line them up with the direction of the transient. Translation of the axes to the point (C_R, C_B) changes (1) and (2) to:

$$S_{R_1}' = H \sin \theta F_i(t) + H \cos \theta F_q(t) \quad (3)$$

$$S_{B_1}' = H \cos \theta F_i(t) - H \sin \theta F_q(t). \quad (4)$$

To rotate the axes by θ degrees, we use the transformation equations:

$$S_{R_2}' = S_{R_1}' \cos \theta - S_{B_1}' \sin \theta$$

$$S_{B_2}' = S_{R_1}' \sin \theta + S_{B_1}' \cos \theta$$

which reduce equations (3) and (4) to

$$S_{R_2}' = HF_q(t) \quad (5)$$

$$S_{B_2}' = HF_i(t). \quad (6)$$

Equations (5) and (6) show that the shape of this subcarrier transient path at the receiver is always the same, regardless of its angle or the location of its center point.[8] The position of the receiver color point in the direction of the transient is given by $HF_i(t)$ while its excursion to the side is given by $HF_q(t)$.

[8] P. W. Howells, "Brightness Errors in the NTSC System," Report to Ceiling Performance Subcommittee of NTSC Panel 13; February, 1952.

Fig. 5(c) shows a subcarrier transient for a case analyzed by Kerr.[5] The conditions are 1-mc bandwidth for each color difference signal, 3.89-mc subcarrier, step-type vestigial sideband filter, and linear phase. If the transient occurs in the opposite direction, or if color phase alternation is used, the sign of the quadrature component is reversed and the transient path is reversed about the line between its end points as shown by the dotted lines in Fig. 5(d). The timing dots shown on the transient path are $\frac{1}{8}$ μsec apart (approximately the rise time of the luminance transient).

Subcarrier Transient Path—Case 2

In the acuity-matching system finally adopted by the NTSC, the color subcarrier frequency is reduced to 3.58 mc and one of the color difference signals is restricted to approximately 0.5-mc bandwidth so that it may be transmitted as a double sideband signal. The other color difference signal is allowed a bandwidth of 1.5 mc and is transmitted as a vestigial sideband signal. With proper design of the transmission path, quadrature components in both signals as detected may be eliminated.

Good results may be obtained by making S_R' the vestigial sideband component of the subcarrier. However, it has been found[9] that greater subjective sharpness of some color transients is obtained when the vestigial sideband component (I') and the double sideband component (Q') are located 33 degrees in advance of the phase of the S_R' and S_B' components of the subcarrier, respectively.

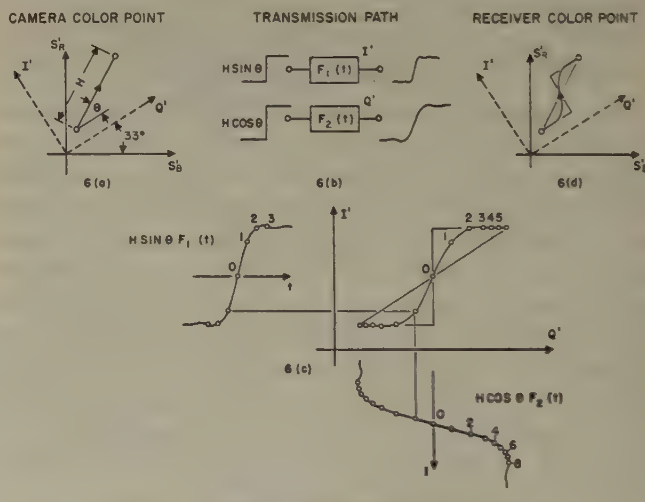

Fig. 6—Subcarrier transient path: Case 2.

Fig. 6 shows a typical shape for the subcarrier transient path of the acuity-matching system. The camera color point (Fig. 6(a)) jumps H units along a line making the angle θ with the Q' axis, so the heights of the steps applied to the I' and Q' channels are $H \sin \theta$ and $H \cos \theta$. Let the unit step responses of the I' and Q' channels (Fig. 6(b)) be $F_1(t)$ and $F_2(t)$ (Fig. 6(c)). Since

[9] NTSC Report No. NTSC-P13-286, "Tests Relating to the Choice of Narrow and Wide Band Components for a Balanced Color Gamut System," (RCA Laboratories), October, 1952.

there is no quadrature response between the color difference channels in this system, the two signals detected at the receiver, neglecting the dc terms, are simply:

$$I' = H \sin \theta F_1(t) \tag{7}$$

and

$$Q' = H \cos \theta F_2(t). \tag{8}$$

Figs. 6(c) and 6(d) show the S-shaped transient path parametrically determined by (7) and (8). The S-shape is characteristic of a system having a higher speed of response in one direction than in the other. Unlike the transient path of Case 1, the shape of this transient does depend upon the angle it makes with the Q' axis. For instance, when $\theta=0$ degrees the path is a straight line parallel to the Q' axis and when $\theta=90$ degrees the path is a straight line parallel to the I' axis. When θ becomes greater than 90 degrees, the curve again has an S-shape, but the S is reversed. Reversal of the *direction* of the transient, however, does not reverse the S-curve.

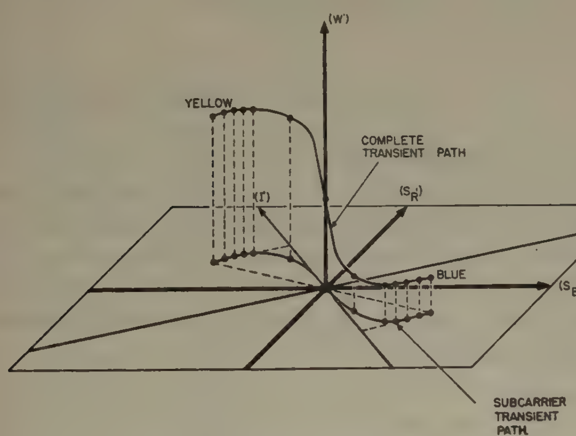

Fig. 7—Complete color transient path.

Complete Color Transient

The complete color transient is the result of combining the monochrome signal transient with the subcarrier transient response just described. Fig. 7 shows such a transient path. The projection of this three dimensional path on the horizontal subcarrier plane is the subcarrier transient response, while the height of the path above the base plane is determined by the transient response of the monochrome channel. Note the centers of all three transients (I', Q', W') coincide in time.

Evaluation of Transients

The factors governing the color transient response of the system are illustrated by Figs. 2 and 7. Fig. 7 shows the three dimensional transient path in terms of coordinate axes representing the transmission primary signals, while Fig. 2 illustrates the relation between these signals and the colorimetric quantities produced at the receiver display. Since we do our calculations on two-dimensional paper, however, these sketches are more useful for visualization of the system behavior than they are for computation.

For computation, the three-dimensional electrical response of the system (in terms of variables W', I', Q') should be changed to normalized form (S_R'/W', S_B'/W') so the resulting luminance and chromaticity transients may be determined with the aid of the normalized luminance factor and chromaticity diagrams shown in Figs. 3 and 4.

Specifically, the method of determining a color transient, given its end points, is as follows:

If end points are ($x_1y_1Y_1$) and ($x_2y_2Y_2$):

(a) Plot end points on chromaticity diagram of Fig. 4 and read off the normalized color difference values S_R'/W', S_B'/W', corresponding to these end points.

(b) Plot these end points on the luminance factor diagram of Fig. 3 and read off the subcarrier luminance factors K_{S_1} and K_{S_2} for the end points.

(c) Compute the values of W' for the end points, by substituting the values of K_S and Y into (16a). Use these values, together with the values of S_R'/W', S_B'/W' [step (a)], to determine the end points of the transient in the S_R', S_B', subcarrier plane.

(d) Using the subcarrier transient path shapes of Figs. 5 or 6, plot the subcarrier transient between the end points determined in (c).

(e) Transfer the subcarrier transient to the normalized subcarrier plane by dividing the co-ordinates of each timing dot by the corresponding value of W'. Since the interval between timing dots shown on the subcarrier transients of Figs. 5 and 6 is equal to the rise time of the luminance transient, W' is near its initial value up to the time $t=-1/2$ interval, and its final value at any time later than $t=+1/2$ interval. At $t=0$, the value of W' is the mean of its initial and final values.

(f) Plot the normalized subcarrier transient in Fig. 4, and read off the values of x and y corresponding to each time point. These determine the chromaticity transient.

(g) Plot the normalized subcarrier transient in Fig. 3 and read off the values of K_S for each time point. These values, together with the corresponding values of W' may be substituted into (16a) to determine the luminance transient.

Results

Using the method outlined, specific color transient responses may be evaluated for any case in which the transient responses of the individual signal channels are known. Several transients have been so evaluated for the two systems previously described.

In Case 1, both color difference signals have a short rise-time but each contributes a sluggish quadrature component to the other. In Case 2, the system adopted by NTSC, these quadrature components have been eliminated. The rise-time of one of the color difference signals has been decreased; that of the other increased.

For comparison of the systems, two main types of color transient are shown: transients from saturated colors to de-saturated colors, and transients between saturated colors. The first type cuts across the constant luminance contours of the subcarrier plane (Fig. 3) while the second type runs more or less along these contours. The effect of the quadrature component of Case 1 is quite different in these two instances.

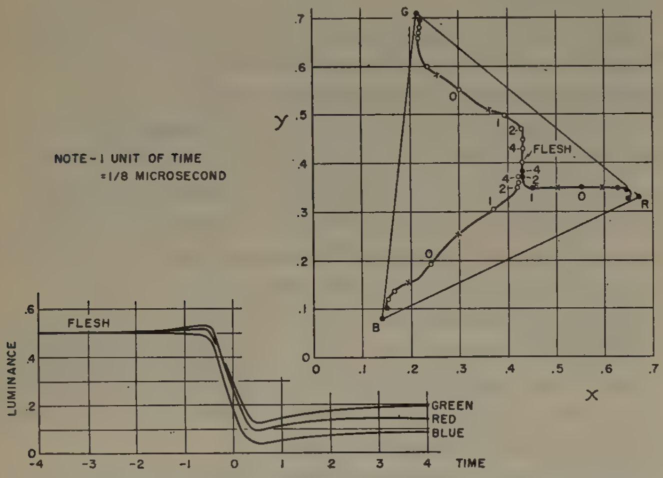

Fig. 8—Color transient in luminance and chromaticity: Case 2.

Figs. 8 and 9 show the transient response with Case 2 and Case 1 transmission, respectively, for the transitions from a saturated color to a flesh color. In the chromaticity transients, the timing dots are spaced at intervals of $\frac{1}{8}$ μsec. The crosses on the transient path indicate the start and finish of the monochrome signal transient.

The chromaticity transients for Case 2 (Fig. 8) show how this system takes advantage of the color perception characteristics of the eye. McAdam's data[10] on equally noticeable chromaticity differences at constant luminance indicate that in the central region of the chromaticity diagram the direction of minimum perceptibility lies more nearly along the y than the x axis. Note how, for all three transients, the relatively slow approach to (or departure from) flesh color is made in this direction of low sensitivity. This feature enhances the subjective sharpness of these transients. If we assume that, for the small area of the color transition involved, a change in y of 0.03 is just perceptible, we see that the elapsed time from the center of the transient to its end at a chromaticity not noticeably different from flesh color is 2 units of time for the transient from red, and four units each for green and blue.

The chromaticity transient of Fig. 9 shows the response of the Case 1 system to the transient from flesh color to red. The dotted curve shows the path taken when the transition occurs in the reverse direction (or the path taken on odd fields when color phase alternation is used).

Note here that from the center of the transient to the final chromaticity, three units of time have elapsed, but that the color point overshoots by a perceptible amount and does not return until after six units of time. This overshoot is produced by the trailing negative peak of the quadrature component. Depending on the direction

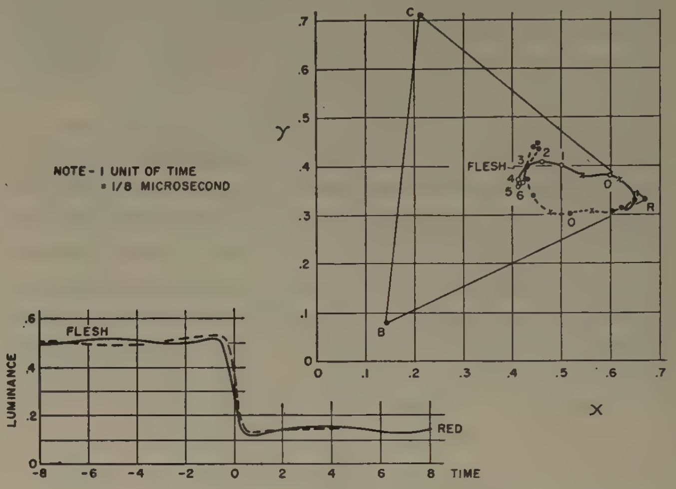

Fig. 9—Color transient in luminance and chromaticity: Case 1.

of the line between the end points of the transient, the overshoot of Case 1 may occur in any direction; not necessarily in the direction of least perceptibility.

The luminance transients shown in Figs. 8 and 9 show a minor contribution from the subcarrier transient. A small leading white and trailing black may be seen in all four transients due to this effect.

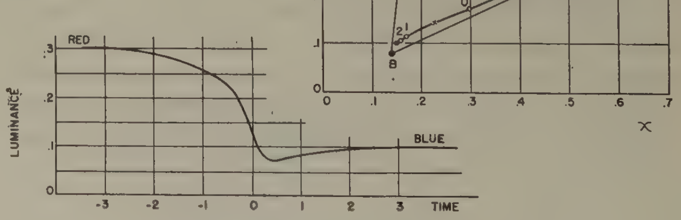

Fig. 10—Color transient in luminance and chromaticity: Case 2.

Fig. 10 shows, for Case 2, a transient between a fairly saturated red and blue, in which the subcarrier transient exerts a greater effect on the luminance transient. In actual color pictures, such a transition would rarely occur, but it is included to show an interesting difference between the two systems. The chromaticity tran-

[10] D. L. McAdam, "Quality of color reproduction," PROC. I.R.E., vol. 39, pp. 468–485; May, 1951.

sient in this case is very good; the elapsed time from the center of the transient to either end is only two units of time. The luminance transient, however, shows an appreciable anticipatory drop contributed by the subcarrier transient.

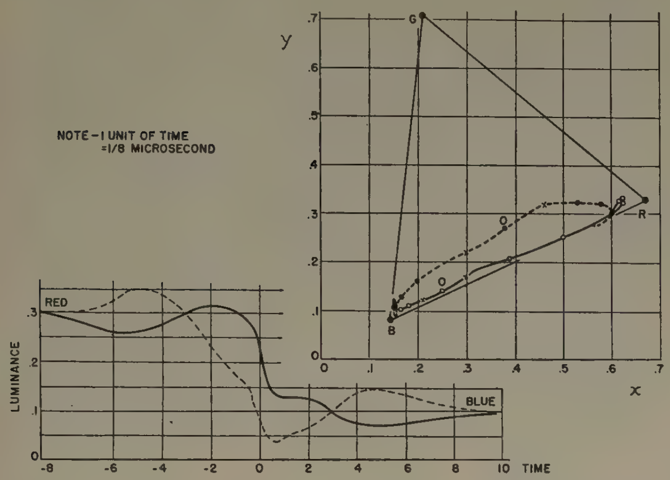

Fig. 11—Color transient in luminance and chromaticity: Case 1.

Fig. 11 shows the response of the system of Case 1 to the same input transient. Here the effect of the subcarrier transient on luminance is pronounced. The reason is this: the direction of this transient is along the luminance contour lines of the subcarrier plane (Fig. 3), so the excursion to the side produced by the quadrature component is across these contour lines in a direction affecting luminance. The impress of the quadrature component wave form on the luminance transient is clearly seen. Note that the two luminance transients (affected by quadrature components of opposite sign) cross at the instant at which the quadrature component is zero. When color phase alternation is used, these two luminance transients replace each other at a 30-cps rate. For such transients between saturated colors, the result may be a quite visible 30-cps luminance flicker occurring at the transition. For color transients involving de-saturated colors, the flicker produced occurs mainly in chrominance and so is not noticeable, but the presence of this luminance "edge flicker," even in rare cases, was one of the important reasons why the system was abandoned.

Conclusions

Comparison of the color transients resulting from the two methods of transmitting the chrominance information yields some interesting conclusions. In Case 2, the reduction in bandwidth of one color difference signal has actually resulted in greater sharpness of the chromaticity transients as well as in a cleaner luminance transient for transitions between saturated colors. Both of these results are due to the elimination of the quadrature components. When a strong quadrature component is present, its effect on chromaticity is such as to require its cancellation by means of color phase alternation. This feature is not necessary in a system where quadrature components have been eliminated by proper filtering as in Case 2.

While tentative conclusions may be drawn directly from a knowledge of the color transient path, its final evaluation must be made subjectively. This may be done either by direct experiment with a color system or by reference to data on color perception, such as have been published by McAdam.[10] The final test is, of course, the appearance of color transitions in an actual color television picture. The excellent results which have been obtained with the relatively simple system of Case 2 are the most convincing evidence so far of the quality of the color transient response of this system.

Appendix I

Co-ordinate Transformations in NTSC Specifications

Note: The following transformations may be used for either colorimetric quantities or electrical signals representative of them. The same transformations are used in the linear case (gamma = unity) as in the gamma corrected case, for which all the variables are primed.

New Transmission Primaries:

$$\begin{bmatrix} I \\ W \\ Q \end{bmatrix} = \begin{bmatrix} .596 & -.274 & -.322 \\ .299 & .587 & .114 \\ .211 & -.523 & .312 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{9}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} .956 & 1 & .621 \\ -.272 & 1 & -.647 \\ -1.106 & 1 & 1.703 \end{bmatrix} \begin{bmatrix} I \\ W \\ Q \end{bmatrix}. \tag{10}$$

Old Transmission Primaries:

$$\begin{bmatrix} S_R \\ W \\ S_B \end{bmatrix} = \begin{bmatrix} .615 & -.515 & -.100 \\ .299 & .587 & .114 \\ -.147 & -.289 & .436 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{11}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1.14 & 1 & 0 \\ -.581 & 1 & -.394 \\ 0 & 1 & 2.03 \end{bmatrix} \begin{bmatrix} S_R \\ W \\ S_B \end{bmatrix}. \tag{12}$$

Where

$$S_R = \frac{R - W}{1.14}, \qquad S_B = \frac{B - W}{2.03}.$$

Old and New Chrominance Primaries:

$$\begin{bmatrix} S_R \\ S_B \end{bmatrix} = \begin{bmatrix} .839 & .545 \\ -.545 & .839 \end{bmatrix} \begin{bmatrix} I \\ Q \end{bmatrix} \tag{13}$$

$$\begin{bmatrix} I \\ Q \end{bmatrix} = \begin{bmatrix} .839 & -.545 \\ .545 & .839 \end{bmatrix} \begin{bmatrix} S_R \\ S_B \end{bmatrix}. \tag{14}$$

Where

$$\sin 33 = .545$$
$$\cos 33^\circ = .839.$$

Appendix II

Luminance Factor Map of Subcarrier Plane

The subcarrier plane shown in Fig. 2 is the surface obtained by setting the luminance (W') signal equal to some constant. The gamma precorrected primary signals, R', G', B', which are applied to the display device of the receiver are then obtained from the transmission primary signals by means of the linear transformation of (10) or (12). Given these input voltages, the display device produces Panel 7 primary lights R, G, and B proportional to the γth power of R', G' and B'. The total luminance (Y) on the screen of the display device is obtained by adding the primary lights, each weighted by the proper luminosity coefficient. That is:

$$\begin{aligned} Y &= 0.299R + 0.587G + 0.114B \\ &= 0.299(R')^{\gamma} + 0.587(G')^{\gamma} + 0.114(B')^{\gamma}. \end{aligned}$$

Substituting the values of R', G' and B' obtained from (12), we obtain

$$\begin{aligned} Y = {} & 0.299(1.14S_R' + W')^{\gamma} \\ & + 0.587(-.581S_R' + W' - .394S_B')^{\gamma} \\ & + .114(W' + 2.03S_B')^{\gamma}. \end{aligned} \tag{15}$$

If we divide both sides of this equation by W'^{γ}, we obtain the expression

$$\begin{aligned} Y/W'^{\gamma} = {} & .299(1.14S_R'/W' + 1)^{\gamma} \\ & + .587(-.581S_R'/W' + 1 - .394S_B'/W')^{\gamma} \\ & + .114(1 + 2.03S_B'/W')^{\gamma}. \end{aligned} \tag{16}$$

We may write this as

$$Y/W'^{\gamma} = K_S, \tag{16a}$$

where K_S is a factor dependent only on the normalized subcarrier voltages S_R'/W', and S_B'/W'. K_S is the ratio of the reproduced luminance to the γth power of the luminance signal, assuming that all constants of proportionality between electrical and colorimetric quantities are unity. The luminance factor contours of Fig. 3 were obtained by evaluating the right-hand side of (16) for a number of values of S_R'/W' and S_B'/W'.

Appendix III

Chromaticity Map of Subcarrier Surface

The relation between the display primaries and the CIE nonphysical primaries is given by the linear transformation[4]

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1.91 & -0.532 & -0.288 \\ -0.985 & 1.999 & -0.028 \\ 0.058 & -0.118 & 0.898 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}. \tag{17}$$

Since the chromaticity coordinates are given by

$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z} \quad \text{and}$$

$$z = \frac{Z}{X+Y+Z}$$

where $x+y+z=1$, we may substitute into (17) the values

$$X = \frac{x}{y}Y \qquad Z = \frac{z}{y}Y \qquad Z = \frac{(1-x-y)}{y}Y$$

obtaining

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = Y \begin{bmatrix} 1.91 & -0.532 & -0.288 \\ -0.985 & 1.999 & -0.028 \\ 0.058 & -0.118 & 0.898 \end{bmatrix} \begin{bmatrix} \dfrac{x}{y} \\ 1 \\ \dfrac{(1-x-y)}{y} \end{bmatrix}. \tag{18}$$

From (12), we may write the amounts of the display primary lights at the receiver as

$$R = W'^{\gamma}(1 + 1.14S_R'/W')^{\gamma} \tag{19}$$

and

$$B = W'^{\gamma}(1 + 2.03S_B'/W')^{\gamma}. \tag{20}$$

Equating the values of R and B given by (19) and (20) to those given by (18), and solving for S_R'/W' and S_B'/W' yields

$$\frac{S_R'}{W'} = 0.877\left[\frac{1}{y}\frac{Y}{W'^{\gamma}}(2.198x - 0.244y - 0.288)\right]^{1/\gamma} - 0.877 \tag{21}$$

$$\frac{S_B'}{W'} = 0.493\left[\frac{1}{y}\frac{Y}{W'^{\gamma}}(-0.840x - 1.016y + 0.898)\right]^{1/\gamma} - 0.493. \tag{22}$$

Note that the factor (Y/W'^{γ}) in the above expressions is simply K_S. Since contours of this factor in the chromaticity diagram have been evaluated by Applebaum[4] and Livingston,[11] work may be saved by reference to their data. Fig. 4 was plotted using (21) and (22).

Acknowledgement

The writer would like to acknowledge his debt to the work of Sidney Applebaum and J. S. S. Kerr, and to the many contributions by H. A. Samulon.

[11] D. C. Livingston, "Colorimetric properties of gamma-corrected color television systems," I.R.E. Convention Record, part 4, pp. 51–56; 1953.

Transition Effects in Compatible Color Television*

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Summary—Perfect reproduction of a scene by color television requires that three independent colorimetric quantities be known for each point of the picture. The particular three quantities chosen to be transmitted and the bandwidth assigned to each are among the system variables which must be specified. The optimum choice of these parameters is decided principally by subjective rating of the reproduced color picture with particular regard to color and luminance transitions at boundaries in the picture content.

This paper describes an experimental video frequency color television system in which these variables can be isolated and conveniently studied. With this system the make-up of color difference signal packages and their assigned bandwidths are switchable so that an observer can view in sequence and on the same display a picture transmitted utilizing various signal forms.

Investigations using this system suggested that certain undesired luminance variations were the most objectionable feature in the reproduction of the color transitions, and led to the development of a means for predistorting the luminance signal to compensate for these variations in the reproduction. This device will be described in the paper.

Introduction

Any color can be defined by three quantities. In the color television system presently under consideration by the FCC the color of large areas in the reproduced picture are controlled by three independent components of the composite signal, the monochrome component, and two color-carrier components. With a receiver perfectly matched to the standards, it is possible to get perfect color fidelity in the large area colors. The system departs from this ideal, however, at transitions from one color to another and at small area colors or detail. This, of course, is due to the fact that the picture information must be transmitted within a restricted bandwidth. In order to make optimum use of this bandwidth, the three color determining signals transmitted are each limited to differing bandwidths, and in order to compensate for the nonlinearity of the receiver display tubes the color information is predistorted by compensating nonlinear circuitry before transmission. Both of these processes have a significant effect on the appearance of color transitions and areas of detail in the reproduced picture. This paper will discuss the effect on the appearance of color transitions resulting from the processing of the color information in accordance with present practice, and will point out where improvement is possible within the present proposed standards without changing the present type of receiver.

The System

The essentials of the presently used color television system, that relate to the appearance of transitions, are shown in block form in Fig. 1. The upper group of blocks represent the studio and transmitter equipment and the lower group represent the receiver equipment.

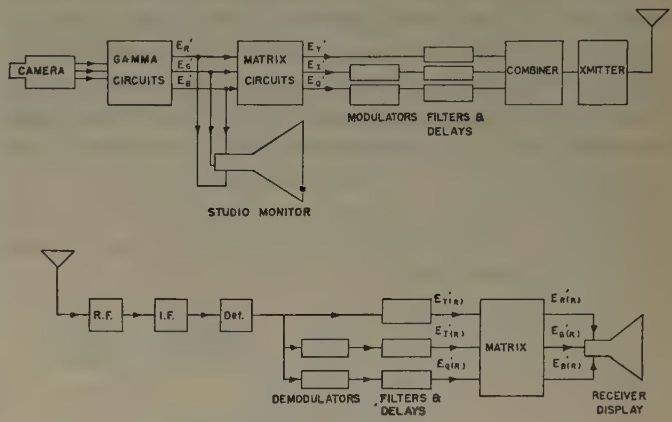

Fig. 1—Block diagram of pertinent system components.

In the studio the camera derives three signals that are instantaneously proportional to the amounts of red, green, and blue light in the scanned image. These are passed through individual gamma-correction circuits that introduce a nonlinearity into the signals that enables the output signals, E_R', E_G', and E_B' to produce a pleasing picture when driving a typical display. The particular relationship between the three signals E_R', E_G', and E_B', and the scene before the camera, for optimum subjective reproduction of the scene is complex. For the purpose of this discussion it is sufficient to say that the camera and gamma circuits are so adjusted that if a monitor display having typical characteristics were connected to the output of the gamma circuits, it would display the desired reproduction of the scene. These typical characteristics are defined in the proposed standards[1] by defining the nonlinear transfer characteristic between the voltage input and the light output that is associated with each primary (a simple power-law characteristic with exponent of 2.2) and the chromaticity of each primary source.

	Red	*Green*	*Blue*
x	0.67	0.21	0.14
y	0.33	0.71	0.08

After gamma correction, the signals are packaged for transmission. First, they are combined in a matrix circuit into three new signals, E_Y', E_I', and E_Q', that are linear combinations of E_R', E_G', and E_B'. These three new signals will be restricted to differing bandwidths in transmission as is shown in Fig. 2. The E_Y' signal is

* Decimal classification: R583. Original manuscript received by the Institute, October 1, 1953.
† Philco Corp., Philadelphia, Pa.

[1] "Final NTSC color standards," *Tele-Tech*, p. 63; September, 1953.

transmitted in the same way as the video signal in present-day monochrome TV and utilizes about the same bandwidth. The other two signals, E_I' and E_Q', are used to modulate two 3.58-mc subcarriers that differ in phase by 90 degrees. With this arrangement, it is possible, with synchronous demodulators, to separate the band-sharing E_I' and E_Q' signals in the frequency range where the modulated signals are transmitted with full double sidebands. This is possible over a range of only 600 kc due to the presence of the sound carrier at 4.5 mc. However, additional bandwidth is available on the low-frequency side of the subcarrier, so that additional high-frequency information of one of the components, E_I', can be transmitted single sideband in this region.

After matrixing, filtering, and modulation, the three components are combined into the composite color signal, and transmitted.

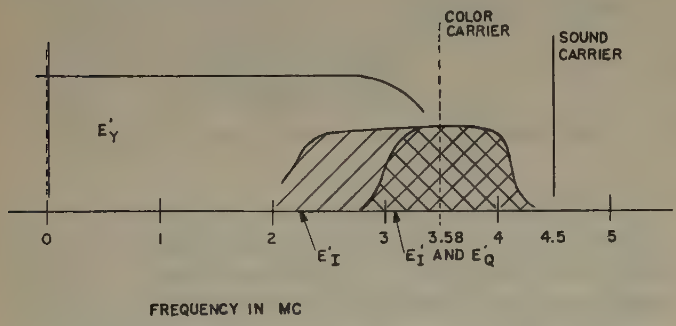

Fig. 2—Video frequency spectrum of composite color signal.

At the receiver the signal is passed through the usual rf and IF amplifiers and is detected. Excepting incidental distortions, the output of the detector is the same as the signal at the transmitter input, represented in the frequency domain in Fig. 2. The E_Y' signal is separated simply by filtering out, to some arbitrary extent, the subcarrier information. The E_I' and E_Q' color video signals are obtained from the output of the synchronous demodulators and appropriate filters. These signals would be replicas of the E_Y', E_I', and E_Q' signals at the output of the matrix circuit in the studio except for the effects of the various filtering operations. They are labeled $E_{Y(R)}'$, $E_{I(R)}'$, and $E_{Q(R)}'$ in Fig. 1 because of these differences. The parenthetical R refers to "receiver." These three signals are passed through a linear matrix that is the inverse of the studio matrix resulting in signals $E_{R(R)}'$, $E_{G(R)}'$, and $E_{B(R)}'$ that, ideally, are the same as the corresponding signals at the studio excepting for the effects of band limitations. These signals are used to drive the receiver display tube, which, we will assume, has the same characteristics as the studio monitor. Thus the picture on the display is identical to that on the studio monitor excepting at areas of detail or at transitions where the effects of the band limitation are evident. The "studio monitor" referred to here is not located at the output of the colorplexer as is the case in the usual studio arrangement. For the purpose of these discussions, we are assuming that it is located at the output of the gamma correction circuits because, at this point the signals have not been filtered and will produce a picture on a wide-band monitor that has the desired appearance with respect to color transitions and detail.

System Analogue

Since this paper is concerned with these transition effects only, we can draw a simplified equivalent diagram of the system. Referring again to Fig. 1, a little thought will show that, ideally, all the circuitry between the transmitter matrix and receiver matrix could be replaced with three equivalent filters. The equivalent filter in the E_Y' channel would have an upper 3-db point around 3.5 mc, the approximate bandwidth of the system assigned to the monochrome signal. The E_Q' channel would have a filter cutting off about 0.6 mc, the highest modulating frequency that can be transmitted double sideband by the subcarrier channel. The equivalent filter in the E_I' channel would pass frequencies up to 1.2 mc, the modulating frequency that corresponds to the lowest frequency sideband in the single sideband part of the subcarrier channel.

During the time when the color television standards were being formulated, there was considerable question about the optimum choice of the make-up of the two subcarrier channel color determining signals and the effective bandwidth to which each should be restricted. In order to evaluate, experimentally, the effects on the appearance of the reproduced picture resulting from particular choices of the aforementioned variables, we built a video frequency analogue to the system.

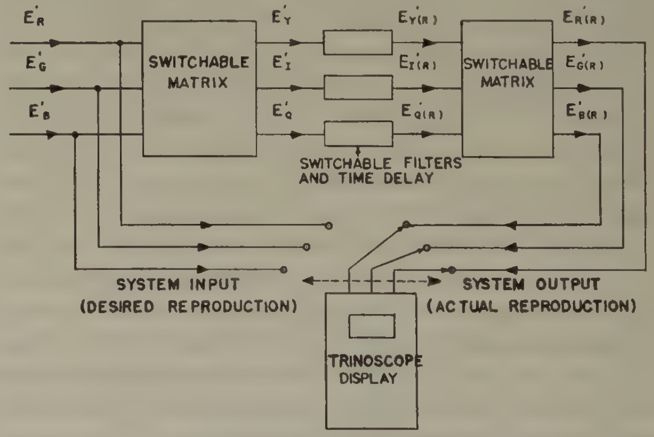

Fig. 3—Block diagram of system analogue.

A block diagram of this analogue is shown in Fig. 3. At the input to this system are the three signals E_R', E_G', and E_B' which, when applied directly to the display produce the "desired" reproduction. These signals are fed into a "switchable matrix." This circuit makes three

new signals which are of the form:

$$E_Y' = 0.30E_R' + 0.59E_G' + 0.11E_B'$$
$$E_I' = a_{11}E_R' + a_{12}E_G' + a_{13}E_B'$$
$$E_Q' = a_{21}E_R' + a_{22}E_G' + a_{23}E_B'.$$

The circuit is arranged in such a way that there are three possible sets of equations available at the flick of a switch, each set corresponding to a different set of coefficients, a_{11} to a_{23}. The make-up of the E_Y' signal is the same in each case. We knew that this particular equation was desired for the E_Y' signal since it is the linear combination of E_R', E_G', and E_B' that is most nearly representative of the luminance of the intended reproduction, and it had been demonstrated that the luminance information should be transmitted with wide bandwidth for optimum reproduction. The second "switchable matrix" circuit is set up to perform the inverse matrixing operation so that its output signals, $E_{R(R)}'$, $E_{G(R)}'$, and $E_{B(R)}'$ will be the same as the input signals except for the effects of the filters. The filters in the E_I' and E_Q' channels have three possible upper frequency limits that are available at the flick of a switch. The filters were designed to have a linear phase characteristic. Incorporated with each was some delay cable which was introduced so that the time delay through each of the three channels, E_Y', E_I', or E_Q', were matched at the input of the second matrix regardless of the particular filter in any channel. This was done experimentally by introducing a square-wave signal at the three system inputs, and adding delay cable in series with the filters until the 50 per cent points in the waveforms at the input to the second matrix were coincident. The possible upper half power points of the filters in the E_I' and E_Q' channels were 0.4 mc, 0.6 mc and 1.2 mc. There was delay equalizing cable in the E_Y' channel, but no frequency limiting filters.

The output signals of the second matrix were fed into a trinoscope display which performs the functions of both the "studio monitor" and "receiver display" of Fig. 1 by virtue of the switch which selects either the system input or output signals as input for the display.

Theoretical Transition Effects

It is instructive to consider the waveforms existing at different points in the system analogue during the time a certain color transition is being scanned and reproduced. To do this mathematically, certain system parameters must be defined. We shall assume that these parameters are set in accordance with the NTSC color signal specifications. Thus, matrix equations are:

$$E_Y' = 0.30E_R' + 0.59E_G' + 0.11E_B'$$
$$E_Q' = 0.41(E_B' - E_Y') + 0.48(E_R' - E_Y')$$
$$E_I' = -0.27(E_B' - E_Y') + 0.74(E_R' - E_Y').$$

We will also assume that the filters are such that the square-wave response of the E_I' channel has one third the rise time of that of the E_Q' channel, and the response of the E_Y' channel is so rapid as to be essentially instantaneous with respect to the other two channels. Furthermore, we assume that the square wave response of the filters is linear between the steady state values. These assumptions concerning the filter behavior, while not corresponding to the actual case, are close enough to it so that the results are qualitatively valid.

The display is assumed to be the type described in the standards, the characteristics of which were discussed previously.

The waveforms in Fig. 4(a) represent those that would be seen in the system analogue at the points noted, when the system is transmitting information corresponding to a green to white transition. The waveforms of

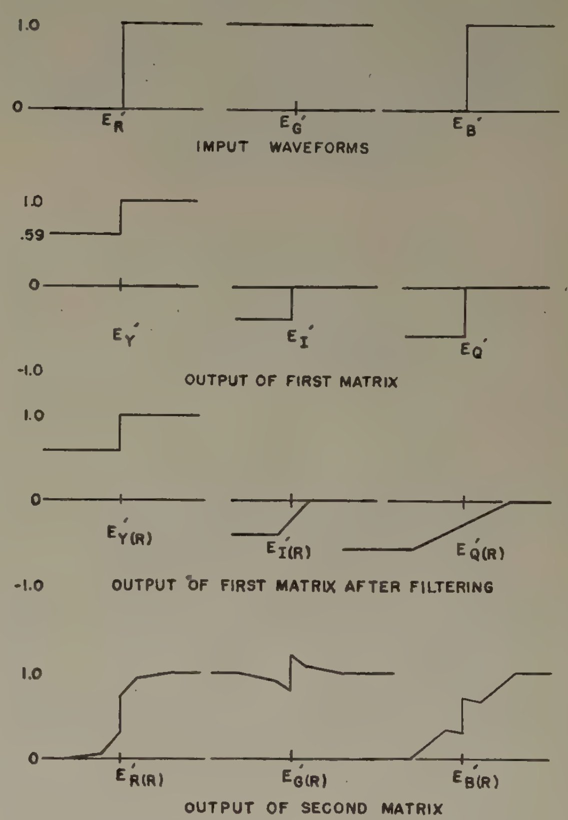

Fig. 4(a)—System analogue waveforms during green to white transitions.

Fig. 4(b) represent the corresponding light distribution on the display as the area corresponding to this color transition is scanned.

It is seen that the input and output waveforms are alike excepting at an interval immediately around the transition. During this interval, which is actually of the order of 1μsec, certain perturbations occur. In Fig. 4(b), these voltage perturbations have been translated into the light perturbations as they occur along the scanned line. This was done by raising the instantaneous values of the receiver voltages, $E_{R(R)}'$, $E_{G(R)}'$, $E_{B(R)}'$ to the 2.2

power. This is necessary to account for the nonlinear transfer characteristic between voltage input and light output that is associated with each electron gun in the display.

Since the intensity pattern of each primary color is known along the transition, it is possible to calculate the resultant luminance pattern caused by all three by combining the $R_{(R)}$, $G_{(R)}$, and $B_{(R)}$ patterns in proportion to the luminance contribution coefficients of the three primaries.

$$Y_{(R)} = 0.30R_{(R)} + 0.59G_{(R)} + 0.11B_{(R)}.$$

This is plotted for the green to white transition at the bottom of Fig. 4(b).

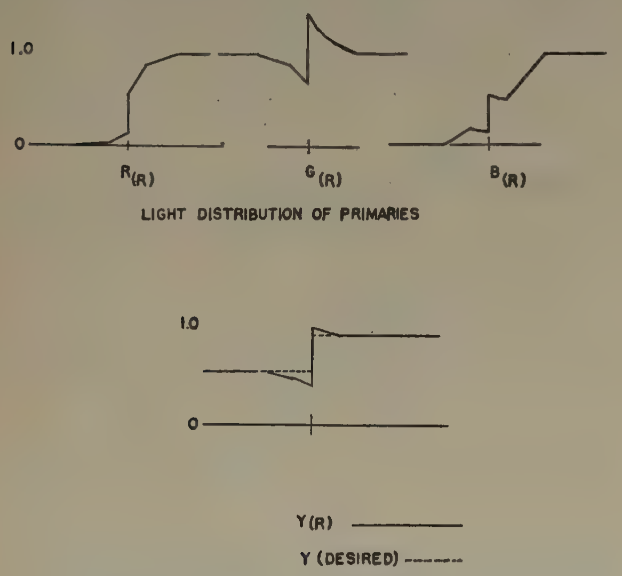

Fig. 4(b)—Light distribution pattern along scanned line of receiver display for a green to white transition.

It is also possible to use the $R_{(R)}$, $G_{(R)}$, and $B_{(R)}$ patterns at the transition to calculate the variations of chromaticity at the transition. This has been done, and the result is seen on Fig. 5. The curving line connecting the green primary to the white point represents the locus of chromaticities at the transition from green to white on the display. The open dots correspond to equidistant points along the scanned line. The dashed portion of the path represents the very rapid change in chromaticity that accompanies rapid change in the $E_{Y'(R)}$ voltage waveform. If the display were driven by the system input signals, the path would be a straight line between these two points and would occur, in its entirety, at the very rapid rate, and the luminance pattern would be that shown dotted in Fig. 4(b). This would be the desired situation.

The locus of chromaticities and brightness patterns for several other transitions are shown in Figs. 5 and 6. Similar illustrations can be found in a paper by Howells.[2]

[2] P. W. Howells, "Transients in color television," IRE Convention Record, part 4, p. 24; 1953.

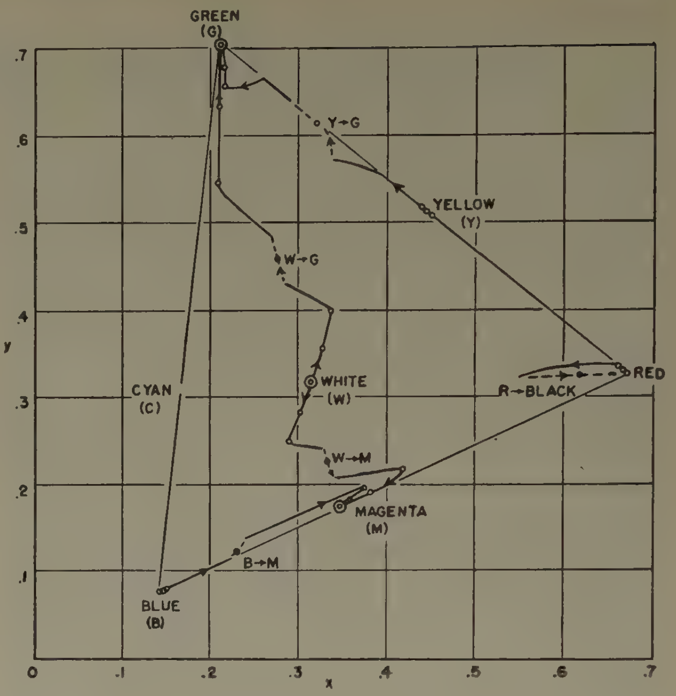

Fig. 5—Paths of receiver chromaticity during certain transitions.

The important thing to be learned from the foregoing is that the system processing causes the actual reproduced color transitions to differ from the desired reproduction in two ways. First, the chromaticity of the display wanders through alien regions as spots preceding and following transitions are scanned, and second, there are undesired perturbations in the luminance pattern preceding and following the transition. These two effects will be considered separately and more generally.

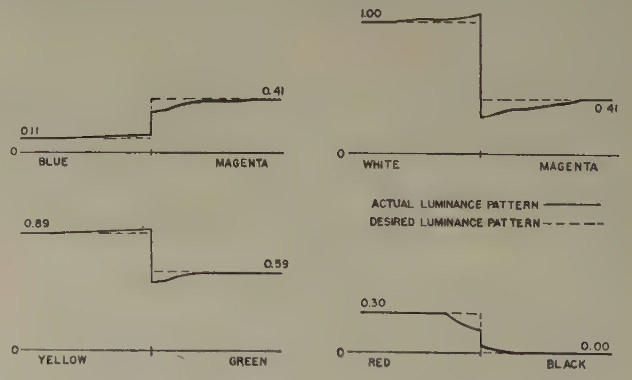

Fig. 6—Receiver brightness pattern for certain transitions.

Chromaticity Distortions

For a given pair of equations for E_I' and E_Q' it is possible to plot a grid of lines on a conventional chromaticity diagram that define chromaticity in terms of E_I'/E_Y' and E_Q'/E_Y'.[3] This is done in Fig. 7 for the particular equations defined in the NTSC specifications.

[3] F. J. Bingley, "Colorimetry in color television, part III," NTSC Tech. Mono. no. 8 (NTSC-P12-344); pp. 48–51; this issue.

The lines are seen to be curved and show a tendency to bunch up at the lower luminosity primaries, red and blue. This is due to the nonlinearities that are introduced into the system by the display. From this it can be seen that, for these particular equations, one class of chromaticity changes including blue to magenta, magenta to red, cyan to white, cyan to orange, etc. (and the reverse transitions) are controlled primarily by the wider bandwidth E_I' signal, while another class including blue to cyan, cyan to green, magenta to white, etc. are controlled primarily by the narrow bandwidth E_Q' signal, and, naturally, there is a third class for which both channels exert considerable control. Changes that are primarily controlled by the wider band E_I' signal will be sharper than others. This statement applies only to the chromaticity component of the color change. The luminance component, which is primarily controlled by the wide-band E_Y' signal is not being considered here.

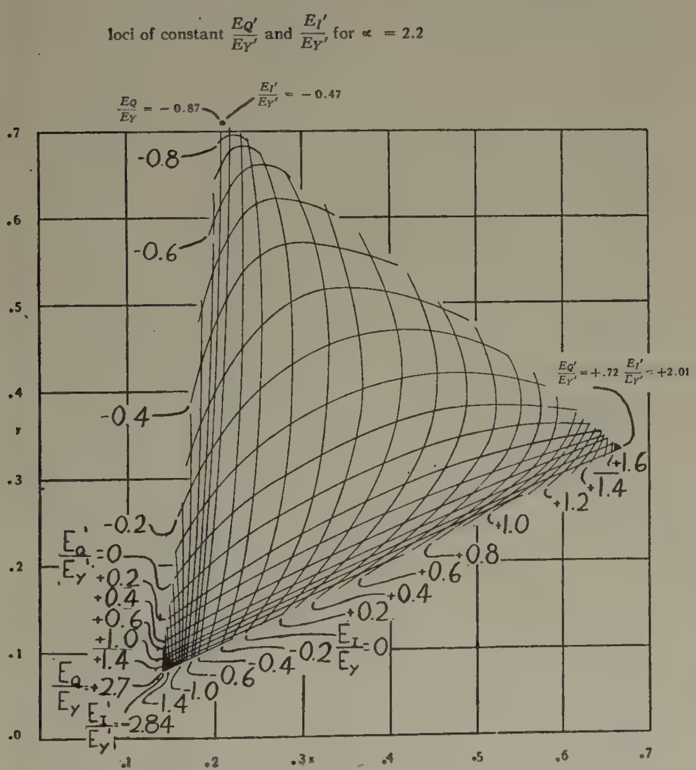

Fig. 7—Loci of constant E_I'/E_Y' and E_Q'/E_Y' for $\propto = 2.2$.

The choice of matrix equations defines the particular directions of chromaticity change that are controlled by the E_I' or E_Q' signals. It is possible, with the system analogue, to select a particular direction of chromaticity change that is to be preferred and another direction that is not, and set up the matrix circuit so that the E_I' and E_Q' signals control chromaticity changes in these particular directions. Three such sets of matrix equations can be set up in the first switchable matrix, and their inverse in the second and comparisons of the results of these three different types of processing can then be observed on the display of the flick of a switch.

Earlier investigations had suggested that a preferred direction for the wider band handling lay generally in the orange to cyan direction[4] as shown in Fig. 7. Our experiments confirmed this, although it should be stated that, from our experience, the choice didn't seem very critical. There was a wide range of choices of equations that gave results that were subjectively quite similar. Because of this, we couldn't get valid quantitative data on an optimum choice. Generally, we found that certain markedly detrimental edge effects were avoided if the wide band and narrow-band directions were not at a small angle with respect to each other in the white region, and a slight over-all improvement was noted if the narrow-band direction was made to be generally from magenta to green. The system defined in the NTSC specifications fulfills both these requirements plus the additional requirement that we didn't find any arrangement superior in these respects.

Luminance Distortions

During these experiments we noticed that the luminance perturbations that accompany these chromaticity excursions had a much more detrimental effect on the appearance of a color transition than did the presence of alien chromaticities. This would be expected since the dimensions of these effects, while on the edge of the eye's acuity for chromaticity, were well within the acuity range for brightness detail.

Referring again to Fig. 6, it is seen that in some cases, the discrepancy between the actual and the desired luminance reproduction is a substantial percentage of the total luminance. This effect is quite visible in the reproduced picture giving the effect of smear or overshoot.

The desired luminance pattern (the luminance pattern on the "studio monitor") can be defined for the NTSC system in terms of the system input signals as follows:

$$Y = \frac{1}{k}(0.30R + 0.59G + 0.11B)$$

where

$$R = (E_R')^{2.2} \qquad G = (E_G')^{2.2} \qquad B = (E_B')^{2.2}$$

and k is a constant.

For the monochrome channel to have complete control of receiver luminance, and at the same time have a system with correct large-area color fidelity, the monochrome signal would have to be a function of Y only (such as $kY^{1/2.2}$). This is impossible if the signal consists

[4] R. D. Kell and A. C. Schroeder, "Optimum utilization of the radio frequency channel for color television," *RCA Review*, p. 133; June, 1953.

of linear combinations of E_R', E_G', and E_B' which are the signals necessary to drive the individual display primaries. The signal actually used, E_Y', is equal to $kY^{1/2.2}$ when the color being reproduced is white ($E_R'=E_G'=E_B'$) and is approximately equal to it for a fairly large range of colors about white, but departs considerably from it at the sides of the triangle of primaries. This is shown clearly in Fig. 8. Here the ratio of $E_Y'/kY^{1/2.2}$ is plotted as a function of the chromaticity of the color intended to be reproduced. This ratio is called the luminance index.

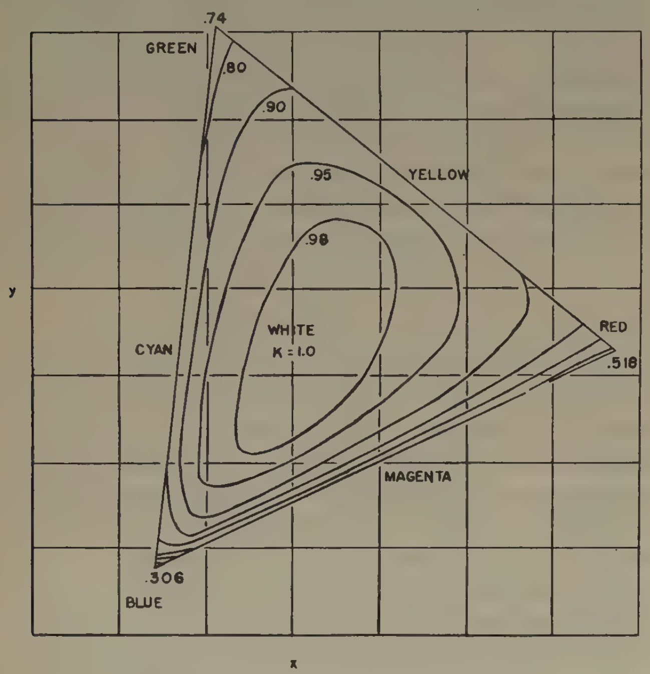

Fig. 8—Loci of constant $E_Y'/(kY)^{1/2.2}$.

This same map can be used to study the actual receiver behavior, including transition effects. The luminance index can be considered to be the ratio of $E_{Y(R)}'$ to the 2.2 root of the actual reproduced luminance if the chromaticity is considered to be the actual reproduced chromaticity. With this in mind, it is easy to deduce which transitions will exhibit the undesired luminance perturbations. Preceding and following transitions, there is the interval where $E_{I(R)}'$ and $E_{Q(R)}'$ waveforms are changing and the $E_{Y(R)}'$ waveform is not. This causes the reproduced chromaticity to wander as is shown in Fig. 5. If in its wandering, the reproduced chromaticity cuts through regions where the luminance index changes considerably, it is obvious that the reproduced luminance must also change considerably since the monochrome signal, $E_{Y(R)}'$, remains constant during these parts of the transition. Thus $E_{I(R)}'$ and $E_{Q(R)}'$ signals exercise some control over the reproduced luminance.

Fig. 8 shows a large area about white where the chromaticity can change without there being an appreciable change in the luminance index. This means that transitions between desaturated colors exhibit a negligible amount of these luminance perturbations. Transitions involving at least one color of near maximum saturation will almost invariably show it to a large degree, particularly transitions involving red or blue of near maximum saturation.

It is possible to minimize the chromaticity excursions that cause this effect by judicious choice of the matrix equations. This is one reason why it was stated previously that the corresponding directions of chromaticity change associated with a given set of matrix equations should not subtend a small angle with each other. The choice of matrix equations in the standards seems good in this respect, but as Fig. 6 shows, the undesired luminance perturbations are still appreciable. Subjectively, they are quite noticeable.

Luminance Correction

It is possible to eliminate, essentially, these unwanted luminance variations by a technique known as "luminance correction." If a signal that is proportional to the difference between the desired luminance pattern and the actual luminance pattern could be derived, it could be introduced in the wide-band monochrome channel in such a way as to compensate for the undesired luminance perturbations. Fig. 9 is a block diagram of a circuit that we have assembled that does this. The upper group of blocks represent conventional studio equipment, with the exception of an adder in the luminance channel and the lower groups represent the circuits that derive the compensating signal called the "luminance-correction signal."

In order to derive a signal proportional to the difference between the actual and desired luminance patterns, $Y_{(R)}$ and Y, the signals $Y_{(R)}$ and Y are formed separately and subtracted. The system analogue is used to form the signals $E_{R(R)}'$, $E_{G(R)}'$ and $E_{B(R)}'$ from the system input signals. These are then each passed through a nonlinear circuit the output of which is approximately proportional to the 2.2 power of the input. As in Fig. 4(b), this operation results in the signals $R_{(R)}$, $G_{(R)}$, and $B_{(R)}$ which, when combined in the proportions 0.30, 0.59 and 0.11, form a signal proportional to the receiver luminance pattern $Y_{(R)}$. The Y signal is formed by passing the E_R', E_G', and E_B' signals through the same type nonlinear circuits and combining them in the same proportions. The resulting signal, Y, is identical to $Y_{(R)}$ excepting at times corresponding to transitions where the $Y_{(R)}$ signal has the undesired perturbations. Thus, the output of the subtracter will be zero except at times corresponding to transitions when the output will be proportional to the luminance perturbations on the receiver display.

If the luminance signal in the composite color signal had linear control of display luminance, the $Y-Y_{(R)}$ signal could simply be added in to effect the desired

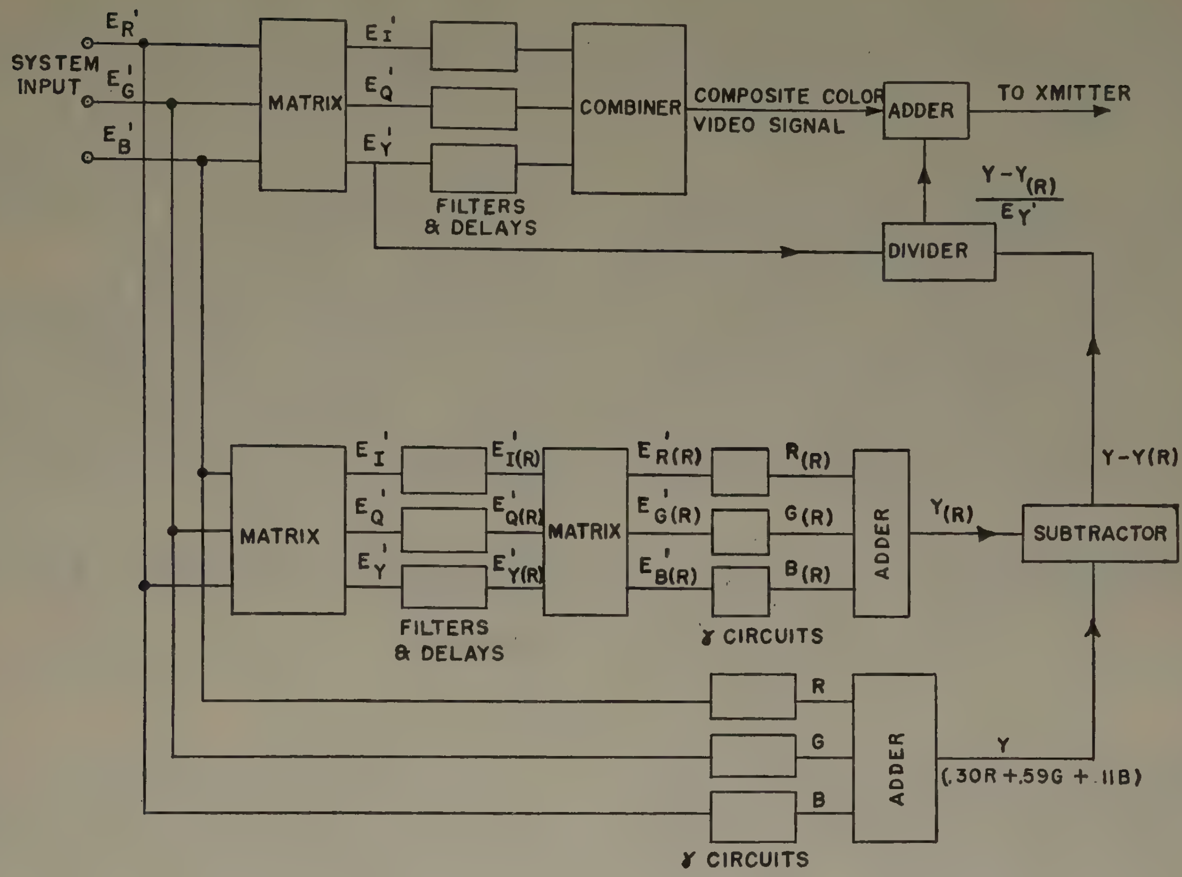

Fig. 9—Block diagram of signal-generating equipment with luminance correction.

compensation. Such, unfortunately, is not the case. The rate of change of display brightness with respect to luminance-channel voltage is, to a good approximation, proportional to E_Y'. Therefore, the luminance-correction signal which is directly proportional to the actual brightness error on the tube must be weighted inversely with E_Y' before it can be applied as voltage in the luminance channel to effect the compensation.

Effects of Luminance Correction on Color Receiver

The addition of the above described luminance-correction signal to the luminance signal can and does eliminate the luminance errors in the receiver display that are caused by subcarrier control of luminance. Subjectively, there is considerable improvement in apparent resolution for scenes that include transitions and detail involving saturated colors. In the absence of luminance correction the luminance errors are most noticeable and objectionable in scenes that include geometrical patterns or lettering as opposed to natural, irregularly shaped objects. These are the scenes that benefit the most from the addition of luminance correction. Even though the luminance errors are not as noticeable in scenes involving natural, irregularly shaped objects, the addition of luminance correction produces a marked sharpening in the appearance of the picture if the scene contains saturated colors.

Effects of Luminance Correction on the Monochrome Receiver

A typical monochrome receiver when driven by the conventional color signal without luminance correction will display a brightness that is proportional to $(E_Y')^\gamma$ where γ is the exponent defining the nonlinear characteristic of the picture tube. The resulting brightness pattern, while not exactly proportional to the desired brightness pattern in the color receiver, is free from the luminance errors that exist at transitions and detail areas in the color picture. Therefore, there is no need for a luminance-correction signal of the type needed by the color receiver. The subjective effect on the monochrome picture of adding luminance correction to the color signal is to introduce edge effects that are similar to those that would be caused by excess peaking of the high-frequency components of the monochrome signal. This effect would be apparent only on those transitions that, in the corresponding color picture, involve at least one color of high saturation. From our experiments with this signal, we have tentatively concluded that this "peaking effect" on the monochrome picture is more often beneficial than it is detrimental to the over-all appearance of the monochrome picture. The effect was observed to be detrimental on only a few scenes involving geometrical patterns or lettering in saturated colors.

Scenes involving irregularly shaped detail in color looked sharper on the monochrome receiver when luminance correction was added.

Conclusions

The presently used type of transmission system for color television signals, that shown in Fig. 1 with system parameters as defined in the NTSC specifications is capable of producing a very pleasing picture. It's most important departure from the desired reproduction seems to be the transition effects described in this paper. The system parameters are so defined in the NTSC specifications that the noticeability of these effects is minimized. Transitions not involving the more saturated colors are almost completely free of these undesired effects, and most transitions involving the saturated colors are reproduced acceptably.

The most objectionable component of the undesired edge effects is the luminance variation that accompanies the slower change in the subcarrier signals. This effect can be compensated for by the technique of luminance correction as described above.

It is believed that the addition of some sort of luminance correction component to the luminance signal is a desirable thing that can significantly enhance the appearance of many scenes. The luminance-correction signal need not be of the particular form described here. A simpler form of luminance-correction process that has approximately the same results should be possible.

Reproduction of Luminance Detail by NTSC Color Television Systems*

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Summary—**To provide information on the relative merits of several methods of gamma correction, three different forms of the NTSC color television system are examined with respect to their ability to reproduce luminance detail. The best system in this respect seems to be one which uses a luminance-corrector in the transmitter, but this system is inferior to the $E_Y^{1/\gamma}$ system in several other respects. The E_Y^1 system seems to be the poorest of the three.**

Introduction

THIS PAPER will compare the performances of three different forms of the NTSC color television system with respect to the reproduction of luminance detail. The systems to be considered are:

(a) the system wherein monochrome signal E_Y' is transmitted,

(b) the system wherein monochrome signal $E_Y^{1/\gamma}$ is transmitted,

(c) the system wherein the transmitted monochrome signal is the result of subtracting the output of a luminance corrector from $E_Y^{1/\gamma}$.

In each case, it will be assumed that the color receiver employed is of "conventional" design, i.e., that it contains no auxiliary corrective circuits.

The analysis will begin with the introduction of a new "system parameter" to supplement those introduced in an earlier paper by this writer.[1] Following derivation of a formula for use in computing this parameter, whose numerical value will measure the fidelity of luminance detail reproduction by a given system, the new parameter will be evaluated over the receiver chromaticity gamut for each of the three systems named above.

Basic Mathematical Formulation

Let the color being viewed by the color television camera at some instant have trichromatic coefficients r, g, b in terms of the NTSC Panel 7 receiver primaries. Let the luminance be Y, and let the total tristimulus value be Σ. Let camera-output signals be E_R, E_G, E_B, such that

$$E_R = \frac{r}{.286}\Sigma \qquad E_G = \frac{g}{.261}\Sigma \qquad E_B = \frac{b}{.453}\Sigma. \tag{1}$$

It follows that at Illuminant C, which is NTSC reference white, $E_R = E_G = E_B = \Sigma$, since $r, g, b = .286, .261, .453$ at this chromaticity.

The monochrome signal will be denoted in general by the symbol E_M, although the symbols

$$E_Y' = .299E_R^{1/\gamma} + .587E_G^{1/\gamma} + .114E_B^{1/\gamma} \tag{2a}$$

$$E_Y^{1/\gamma} = (.299E_R + .587E_G + .114E_B)^{1/\gamma} \tag{2b}$$

will be used to denote specific forms for E_M whenever applicable. γ is the picture tube gamma exponent. Color-difference signals will be denoted by

$$E_{RD} = E_R^{1/\gamma} - E_Y' \qquad E_{GD} = E_G^{1/\gamma} - E_Y'$$
$$E_{BD} = E_B^{1/\gamma} - E_Y'. \tag{3}$$

In all cases to be considered, the chrominance signal will be constructed by modulation of E_{BD} and E_{RD} onto the subcarrier at phases $\phi = 0°$ and $\phi = 90°$, respectively. In a "conventional" NTSC-type color receiver, the reproduced luminance is

$$Y' = .316n[.299(E_{RD} + E_M)^\gamma + .587(E_{GD} + E_M)^\gamma + .114(E_{BD} + E_M)^\gamma], \tag{4}$$

wherein n is a constant the numerical value of which

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[1] D. C. Livingston, "Colorimetric analysis of the NTSC color television system," Proc. I.R.E., pp. 138–151; this issue.

can be adjusted by the viewer. A more convenient form for (4) can be written by introducing the quantity E_{MD}, defined by

$$E_{MD} = E_M - E_Y'. \tag{5}$$

The result is

$$Y' = .316n[.299(E_R^{1/\gamma}+E_{MD})^\gamma + .587(E_G^{1/\gamma}+E_{MD})^\gamma + .114(E_B^{1/\gamma}+E_{MD})^\gamma]. \tag{6}$$

It is to be noted that E_{MD} vanishes when $E_M = E_Y'$.

The basic mathematical formulation is complete, and consideration of luminance detail reproduction proceeds.

Luminance Detail

The response of the color television system to abrupt changes in subject luminance Y can be studied by considering the effect on the electrical signals when the initial luminance Y changes by amount δY in so short a time that the monochrome signal completes its transition of magnitude δE_M before the chrominance signal has changed appreciably. In order to restrict effects entirely to the monochrome channel, it is also feasible to visualize δY as the amplitude of a very short pulse rather than of a step. In this way, one can consider that E_M changes to $E_M + \delta E_M$ and then returns to the value E_M while the chrominance signal does not vary at all. Consequently, all quantities in the following analysis not denoted as increments are to be regarded as constants. Only the increments themselves will be considered to be functions of time and therefore to be representable by spectra extending into the "mixed-highs" region.

An expression will now be found for the change $\delta Y'$ in reproduced luminance corresponding to an abrupt change δY in subject luminance. In (6), it is clear that $E_R^{1/\gamma}$, $E_G^{1/\gamma}$, $E_B^{1/\gamma}$ do not respond at all to δY since these signals have reached the receiver via the chrominance channel. E_{MD}, on the other hand, is seen in (5) to be such that $\delta E_{MD} = \delta E_M$ since the term E_Y' in (5) represents a signal which arrived via the chrominance channel. It follows, then, that the reproduced luminance $Y' + \delta Y'$ corresponding to subject luminance $Y + \delta Y$ is

$$\begin{aligned} Y' + \delta Y' = .316n[&.299(E_R^{1/\gamma} + E_{MD} + \delta E_M)^\gamma \\ &+ .587(E_G^{1/\gamma} + E_{MD} + \delta E_M)^\gamma \\ &+ .114(E_B^{1/\gamma} + E_{MD} + \delta E_M)^\gamma]. \end{aligned} \tag{7}$$

$$F_d = \left(\frac{\delta Y}{Y}\right)^{-1} \frac{.299[(e_R^{1/\gamma} + e_{MD} + \delta e_M)^\gamma - (e_R^{1/\gamma} + e_{MD})^\gamma] + \cdots}{.299(e_R^{1/\gamma} + e_{MD})^\gamma + \cdots} \tag{14}$$

Subtracting (6) from (7) leaves

$$\begin{aligned} \delta Y' = .316n\{&.299[(E_R^{1/\gamma}+E_{MD}+\delta E_M)^\gamma - (E_R^{1/\gamma}+E_{MD})^\gamma] \\ &+ .587[(E_G^{1/\gamma}+E_{MD}+\delta E_M)^\gamma - (E_G^{1/\gamma}+E_{MD})^\gamma] \\ &+ .114[(E_B^{1/\gamma}+E_{MD}+\delta E_M)^\gamma - (E_B^{1/\gamma}+E_{MD})^\gamma]\} \end{aligned} \tag{8}$$

as the exact expression for the incremental change $\delta Y'$ in displayed luminance when the monochrome signal changes by amount δE_M in response to a change δY in subject luminance.

Now, since the perceptibility of brightness changes is known to be measurable by $\delta Y'/Y'$ rather than by $\delta Y'$ alone (except at extreme values of Y'), it will be useful to deal with $\delta Y'/Y'$ and $\delta Y/Y$ rather than with $\delta Y'$ and δY. In particular, it will be convenient to use the ratio

$$F_d \equiv \frac{\left(\frac{\delta Y'}{Y'}\right)}{\left(\frac{\delta Y}{Y}\right)} \tag{9}$$

as a measure of the fidelity of the color television system with respect to reproduction of luminance detail. This same ratio has also been used recently by Loughlin[2] to measure accuracy of luminance detail reproduction. F_d will be assigned the name *Luminance Detail Fidelity* and be regarded as a new "system parameter."

Evidently, perceptibility of luminance detail in the reproduced picture and in the original subject will be equal when the value of F_d is unity.

It is desired to form an expression for F_d in terms of electrical signals, but it will first be convenient to convert to normalized variables by substituting

$$E_R = e_R \Sigma \qquad E_G = e_G \Sigma \qquad E_B = e_B \Sigma \tag{10}$$

for the camera-output signals and through equivalent substitutions for E_M, E_{MD}, and δE_M. The normalized variables e_R, e_G, e_B and e_M, e_{MD}, δe_M have the property of being functions of chromaticity alone, so that they can be plotted on chromaticity diagrams. If, as in all cases to be considered in this paper, E_M can be expressed

$$E_M = e_M \Sigma^{1/\gamma}, \tag{11}$$

with e_M independent of luminance, then

$$E_{MD} = e_{MD} \Sigma^{1/\gamma}. \tag{12}$$

The relation

$$\delta E_M = \Sigma^{1/\gamma} \delta e_M \tag{13}$$

is not obviously meaningful, but it will be found to be meaningful and applicable in each case to be considered in this paper.

Substituting (10), (11), (12), and (13) into (6) and (8), then substituting (6) and (8) into (9), one finds

as a general working formula for F_d. To conserve space, dots are used to represent terms in e_G and e_B analogous to those in e_R. One might desire to replace δe_M to (14)

[2] B. D. Loughlin, "Comments on 'optimum' gamma correction for NTSC color signal," prepared for NTSC Panel 13 Gamma Subcommittee; Feb. 18, 1953.

with an expression containing $\delta Y/Y$, but this cannot be done in general form. Instead, it must be done separately for each specific E_M function. Perhaps a word of warning is in order in regard to the meaning of the quantity δe_M. δe_M does *not* represent an increment in e_M resulting from an increment δY in subject luminance Y; for, by definition, e_M is independent of Y. The proper key to the meaning of δe_M is (13), which must be regarded as a *definition* of δe_M as the normalized equivalent of δE_M.

$$F_d[E_Y'] = \left(\frac{\delta Y}{Y}\right)^{-1} \frac{.299[(e_R^{1/\gamma}+\delta e_Y')^\gamma - e_R] + \cdots}{.299e_R + .587e_G + .114e_B}, \quad (19)$$

which is valid for any value of $\delta Y/Y$. In the case for $\delta Y/Y = 0+$, (18) reduces to

$$\delta e_M = \frac{e_Y'}{\gamma}\,\frac{\delta Y}{Y}, \quad (20)$$

and (15) gives

$$F_{d0}[E_Y'] = e_Y'\,\frac{.299e_R^{1-1/\gamma} + .587e_G^{1-1/\gamma} + .114e_B^{1-1/\gamma}}{.299e_R + .587e_G + .114e_B}, \quad (21)$$

It can be noted, since e_R, e_G, e_B and e_{MD} are functions of chromaticity alone while δe_M is a function of $\delta Y/Y$ as well, that F_d as given by (14) is a function of $\delta Y/Y$ in addition to being a function of chromaticity. Moreover, there seems to be no sound justification for arbitrarily assuming $\delta Y/Y$ to be vanishingly small. On the other hand, it will be shown later that, at least for $E_M = E_Y'$ and $E_M = E_Y^{1/\gamma}$, the variation of F_d with $\delta Y/Y$ is slow enough so that the value when $\delta Y/Y = 1$ differs by only a few per cent from that when $\delta Y/Y = 0+$. Hence, it will be worthwhile to reduce (14) to the form which results when $\delta Y/Y \to 0$. F_d in this limiting case will be denoted by F_{d0}. To find F_{d0} from (14), one must first recognize that δe_M, by its nature, goes to zero as $\delta Y/Y \to 0$. Thus (14) immediately yields

$$F_{d0} = \gamma\delta e_M \left(\frac{\delta Y}{Y}\right)^{-1} \frac{.299(e_R^{1/\gamma} + e_{MD})^{\gamma-1} + \cdots}{.299(e_R^{1/\gamma} + e_{MD})^\gamma + \cdots}, \quad (15)$$

in which terms in e_G and e_B are again replaced by dots for convenience. Specific final forms for (14) and (15) will be deduced for each individual type of monochrome signal in later parts of this analysis.

Consideration of specific systems will now proceed.

System Analyses

The E_Y' System

When $E_M = E_Y'$, it follows from (5) that $E_{MD} = 0$, whereupon e_{MD} also vanishes. Expression of δe_M in terms of $\delta Y/Y$ for this case begins by observing that

$$E_M = E_Y' = e_Y'\,\Sigma^{1/\gamma} \quad (16)$$

leads to

$$E_M + \delta E_M = e_Y'(\Sigma + \delta\Sigma)^{1/\gamma} = e_Y'\,\Sigma^{1/\gamma}\left(1 + \frac{\delta Y}{Y}\right)^{1/\gamma} \quad (17)$$

when use is made of the obvious relation $\delta\Sigma/\Sigma = \delta Y/Y$. Subtraction of (16) from (17) and using (13) yields

$$\delta e_M = e_Y'\left[\left(1 + \frac{\delta Y}{Y}\right)^{1/\gamma} - 1\right] \equiv \delta e_Y'. \quad (18)$$

Equation (14) can now be written as

when δe_M is replaced in accordance with (20). This expression closely resembles that found by Loughlin[2] for the E_Y' system, and, as was the case in the expression found by Loughlin, it reduces to

$$F_{d0}[E_Y'] = \left(\frac{e_Y'}{e_Y^{1/2}}\right)^2$$

when $\gamma = 2$.

It will be instructive to consider the variation of F_d with $\delta Y/Y$ at a few selected chromaticities. First, consider Illuminant C, at which

$$e_R = e_G = e_B = 1.$$

Equation (19) reduces straightforwardly to $F_d[E_Y'] = 1$, independently of the magnitude of $\delta Y/Y$. When, for specific chromaticities, saturated red ($r = 1$) and a desaturated red ($r, g, b = .8, .1, .1$) are examined, the results are as shown in Table I.

TABLE I
F_d in E_Y' System for Various Chromaticities and $\delta Y/Y$ Values

$\delta Y/Y$	Chromaticity		
	Ill. C	$r, g, b = .8, .1, .1$	$r = 1.0$
0+	1.000	0.776	0.299
0.1	1.000	.775	.295
1.0	1.000	.770	.278

It is evident that the values at $\delta Y/Y = 1.0$ differ relatively little from those at $\delta Y/Y = 0+$, so it appears that F_{d0} might be of sufficient significance to warrant mapping it over the receiver triangle. The resulting map is given in Fig. 1.

The $E_Y^{1/\gamma}$ System

For $E_M = E_Y^{1/\gamma}$, (5) gives

$$E_{MD} = E_Y^{1/\gamma} - E_Y' \equiv \Delta E_Y. \quad (22)$$

An analysis similar to that which led to (18) now leads to

$$\delta e_M = e_Y^{1/\gamma}\left[\left(1 + \frac{\delta Y}{Y}\right)^{1/\gamma} - 1\right] \equiv \delta e_Y^{1/\gamma}, \quad (23)$$

and (14) becomes

$$F_d[E_Y^{1/\gamma}] = \left(\frac{\delta Y}{Y}\right)^{-1} \frac{.299[(e_R^{1/\gamma} + \Delta e_Y + \delta e_Y^{1/\gamma})^\gamma - (e_R^{1/\gamma} + \Delta e_Y)^\gamma] + \cdots}{.299(e_R^{1/\gamma} + \Delta e_Y)^\gamma + \cdots}. \tag{24}$$

Since

$$\delta e_M = \frac{e_Y^{1/\gamma}}{\gamma} \frac{\delta Y}{Y} \tag{25}$$

when $\delta Y/Y = 0+$, (15) yields

$$F_{d0}[E_Y^{1/\gamma}] = e_Y^{1/\gamma} \frac{.299(e_R^{1/\gamma} + \Delta e_Y)^{\gamma-1} + \cdots}{.299(e_R^{1/\gamma} + \Delta e_Y)^\gamma + \cdots}. \tag{26}$$

As in the previous case, it is readily seen that $F_d[E_Y^{1/\gamma}] = 1$ at Illuminant C for all values of $\delta Y/Y$. Results at other $\delta Y/Y$ values are shown in Table II.

TABLE II

F_d in $E_Y^{1/\gamma}$ System for Various Chromaticities and $\delta Y/Y$ Values

$\delta Y/Y$	Chromaticity		
	Ill. C	$r, g, b = .8, .1, .1$	$r = 1.0$
0+	1.000	0.829	0.575
0.1	1.000	.828	.572
1.0	1.000	.824	.564

The $E_Y^{1/\gamma} - \Delta E_Y^0$ System

This system, in which the transmitted monochrome signal E_M is $E_Y^{1/\gamma}$ minus the luminance-corrector output signal ΔE_Y^0, was suggested by Loughlin.[2] The symbol ΔE_Y^0 is a reminder that the luminance-corrector is intended to produce signal of form ΔE_Y, given in (22).

The basic theory of the luminance-corrector has been described in papers by the Hazeltine Corporation[3] and by the writer.[4] It has been shown by the writer[4] that the general expression for the output of a luminance-corrector is given by

$$\Delta E_Y^0 \cong \frac{\gamma - 1}{2} Q_0 \frac{E_C^2}{E_Y^{1/\gamma}}, \tag{27}$$

in which E_C is the chrominance signal amplitude and Q_0 is a constant. As originally discussed in the above-cited papers, ΔE_Y^0 was intended to be an approximation to ΔE_Y in (22), whereas analysis showed the actual ap-

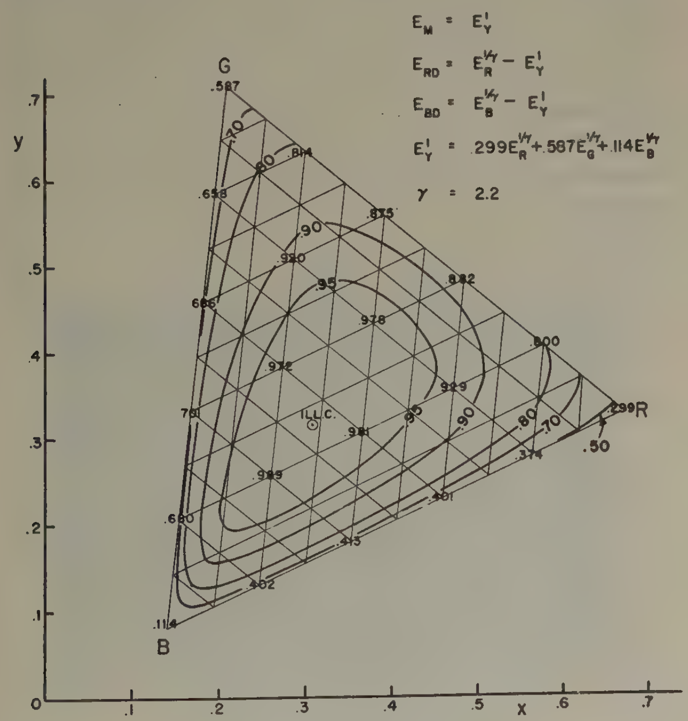

Fig. 1—Luminance detail fidelity F_{d0} in system using signals as indicated.

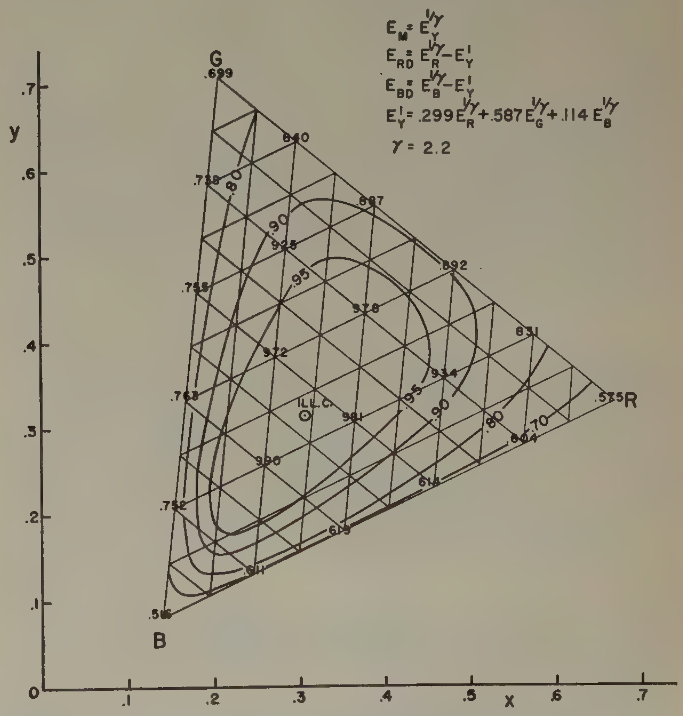

Fig. 2—Luminance detail fidelity F_{d0} in system using signals as indicated.

It again seems worthwhile to evaluate F_{d0} over the receiver triangle, since F_d appears to vary relatively little with $\delta Y/Y$ within a reasonable range of $\delta Y/Y$ values. A map of F_{d0} appears in Fig. 2.

[3] Hazeltine Corp., "Proposal for Modification of the Complete Color Signal to Provide Improved Constant-Luminance Transmission," prepared for Subcommittee 9, NTSC Panel 13; July 25, 1952.

[4] D. C. Livingston, "Colorimetric Analysis of Gamma-Corrected Shunted Monochrome Simultaneous Color Television Systems—Part IV," prepared for NTSC Panel 13; Sept. 26, 1952. (See ref. 1.)

proximate formula for ΔE_Y to be

$$\Delta E_Y \cong \frac{\gamma - 1}{2} Q \frac{E_C^2}{E_Y'}, \tag{28}$$

with E_Y' given by (2a) and Q given by

$$Q = .299 m_R^2 \cos^2 (\theta_R - \phi) + .587 m_G^2 \cos^2 (\theta_G - \phi) + .114 m_B^2 \cos^2 \phi, \tag{29}$$

in which ϕ is the relative phase of the chrominance signal, θ_R and θ_G are demodulation angles for red and green color-difference signals, respectively, while m_R, m_G, m_B are gain factors associated with chrominance components representing the color-difference signals. The significances of (28) and (29) are explained in greater detail elsewhere.[4] The differences between (27) and (28) are dictated by circuital considerations. Thus, the constant Q_0 in (27) replaces the variable Q which appears in (28) because it is assumed that an electrical signal which varies in accordance with Q might be difficult to generate. In the same way, $E_Y^{1/\gamma}$ replaces E_Y' in (27) because $E_Y^{1/\gamma}$ is certainly available in the transmitter whereas E_Y' might not be.

It will be of interest to examine the way in which Q varies with ϕ. This will require determination of m_R, m_G, m_B, θ_R, and θ_G for the standard NTSC chrominance signal, which can be described as

$$E_C\underline{/\phi} = \frac{E_{BD}}{2.03} \underline{/0^\circ} + \frac{E_{RD}}{1.14} \underline{/90^\circ}. \tag{30}$$

Equation (30) states that the chrominance signal consists of the resultant of two components with amplitudes $E_{BD}/2.03$ and $E_{RD}/1.14$ at phases $\phi = 0°$ and $\phi = 90°$, respectively. Now the output of a synchronous demodulator with demodulation angle θ can be denoted by the symbol,

$$E_C\underline{/\phi} \| \theta = E_C \cos (\phi - \theta), \tag{31}$$

whereupon it follows that (30) and the definitions for m_R, m_G, m_B, θ_R, and θ_G, with $\theta_B = 0$, lead to

$$E_{RD} = m_R E_C\underline{/\phi} \| 90^\circ = m_R \frac{E_{RD}}{1.14} \tag{32a}$$

$$E_{GD} = m_G E_C\underline{/\phi} \| \theta_G = m_G \left[\frac{E_{BD}}{2.03} \cos \theta_G + \frac{E_{RD}}{1.14} \sin \theta_G \right] \tag{32b}$$

$$E_{BD} = m_B E_C\underline{/\phi} \| 0^\circ = m_B \frac{E_{BD}}{2.03} \cdot \tag{32c}$$

Equations (32a) and (32c) reveal that $m_R = 1.14$ and $m_B = 2.03$. Moreover, E_{RD}, E_{GD}, E_{BD} are related by

$$.299 E_{RD} + .587 E_{GD} + .114 E_{BD} = 0, \tag{33}$$

so that elimination of E_{GD} between (32b) and (33) yields

$$\left(\frac{m_G \cos \theta_G}{2.03} + \frac{.114}{.587} \right) E_{BD} + \left(\frac{m_G \sin \theta_G}{1.14} + \frac{.299}{.587} \right) E_{RD} = 0. \tag{34}$$

Since E_{BD} and E_{RD} are both arbitrary, their coefficients in (34) must vanish independently. It then quickly follows that

$$m_G = \frac{\sqrt{[.114(2.03)]^2 + [.299(1.14)]^2}}{.587} = .7018$$

and

$$\cos \theta_G = \frac{.114(2.03)}{.587(.7018)} = .5618$$

$$\sin \theta_G = \frac{.299(1.14)}{.587(.7018)} = .8274,$$

whereupon (29) becomes

$$Q = [.299(1.14)^2 - .114(2.03)^2] \sin^2 \phi + .114(2.03)^2 - .587(.7018)^2 [.5618 \cos \phi + .8273 \sin \phi]. \tag{35}$$

A graphical plot of (35) appears in Fig. 3. It is seen that Q varies by a factor of about 6:1 between its maximum and minimum values. This is in marked contrast to the situation for the circular subcarrier[3-4] for which case Q was independent of ϕ. Since the luminance-corrector uses a constant Q_0 instead of the ϕ-dependent Q, it will result that its output will be too large at some hues and too small at others. Consequently, it will not be able to deliver a signal which at all chromaticities is a good approximation to ΔE_Y. This failure will be aggravated by the use of $E_Y^{1/\gamma}$ instead of E_Y' as the dividing signal in (27).

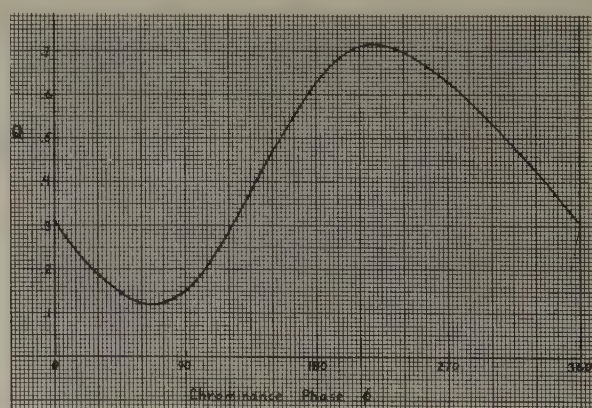

Fig. 3—Variation of Q with ϕ for luminance-corrector in system using noncircular chrominance signal.

The analysis of the properties of the luminance-corrector system with respect to luminance detail will now proceed. For simplicity, it will be restricted to the case for very small $\delta Y/Y$. (15) is to be evaluated. It will be necessary to find expressions for $\gamma \delta e_M$ and e_{MD}. Now,

$$E_M = E_Y^{1/\gamma} - \frac{\gamma - 1}{2 E_Y^{1/\gamma}} Q_0 E_C^2, \tag{36}$$

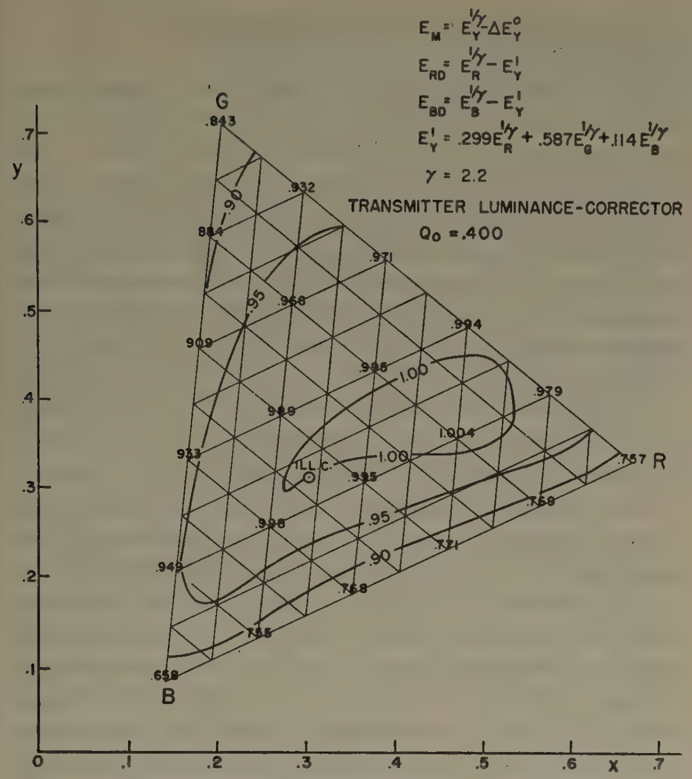

Fig. 4—Luminance detail fidelity F_{d0} in system using signals as indicated.

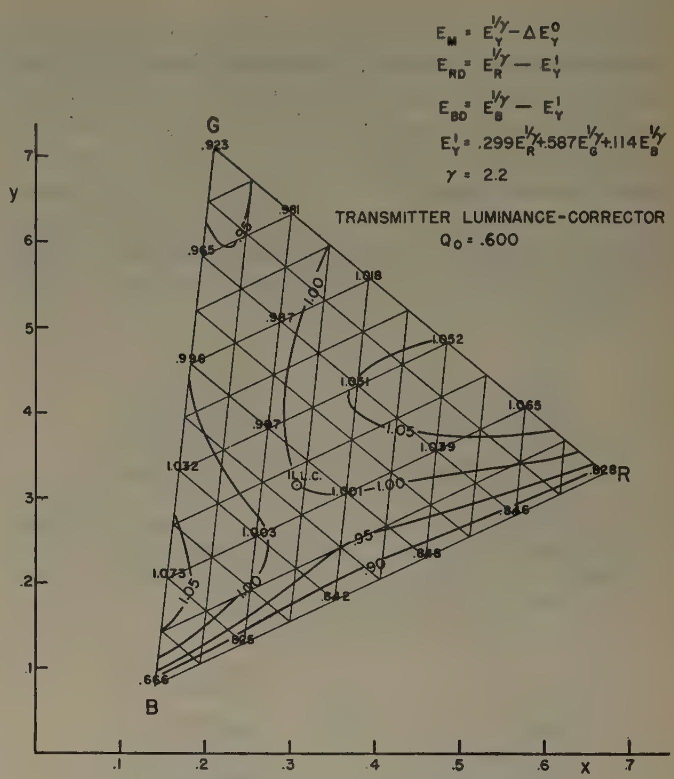

Fig. 5—Luminance detail fidelity F_{d0} in system using signals as indicated.

so it results that

$$E_M + \delta E_M = E_Y{}^{1/\gamma}\left(1 + \frac{\delta Y}{Y}\right)^{1/\gamma} - \frac{\gamma - 1}{2E_Y{}^{1/\gamma}} Q_0 E_C{}^2 \left(1 + \frac{\delta Y}{Y}\right)^{-1/\gamma}. \tag{37}$$

Equation (37) follows from the fact that the change in $E_Y{}^{1/\gamma}$ caused by the fluctuation $\delta Y/Y$ is as given in (23). E_C, being limited to slow variations, does not respond to subject luminance detail. Subtracting (36) from (37), letting $\delta Y/Y \ll 1$, and introducing normalized variables from (11), (13), and

$$E_C = e_C \Sigma^{1/\gamma},$$

$\gamma \delta e_M$ is found to be given by

$$\gamma \delta e_M = \left(e_Y{}^{1/\gamma} + \frac{\gamma - 1}{2e_Y{}^{1/\gamma}} Q_0 e_C{}^2\right)\frac{\delta Y}{Y}. \tag{38}$$

Next, e_{MD} is to be found. Eq. (5), (22), and (36) give

$$E_{MD} = \Delta E_Y - \frac{\gamma - 1}{2E_Y{}^{1/\gamma}} Q_0 E_C{}^2,$$

which, upon normalization, becomes

$$e_{MD} = \Delta e_Y - \frac{\gamma - 1}{2e_Y{}^{1/\gamma}} Q_0 e_C{}^2. \tag{39}$$

Finally, (15), (38), (39) may be combined, result being

$$F_{d0}[E_Y{}^{1/\gamma} - \Delta E_Y{}^0] = \left(e_Y{}^{1/\gamma} + \frac{\gamma - 1}{2e_Y{}^{1/\gamma}} Q_0 e_C{}^2\right) \frac{.299\left(e_R{}^{1/\gamma} + \Delta e_Y - \frac{\gamma - 1}{2e_Y{}^{1/\gamma}} Q_0 e_C{}^2\right)^{\gamma - 1} + \cdots}{.299\left(e_R{}^{1/\gamma} + \Delta e_Y - \frac{\gamma - 1}{2e_Y{}^{1/\gamma}} Q_0 e_C{}^2\right)^{\gamma} + \cdots}. \tag{40}$$

Equation (40) can be evaluated over the receiver triangle following assignment of a numerical value to Q_0. This value, evidently, should lie between the extreme values shown for Q in Fig. 3, and should be located through the use of some scheme for weighting the various Q values in accordance with the frequency of occurrence of the corresponding ϕ values in typical pictorial material.

Figs. 4 and 5 show the results of calculating F_{d0} from (40) for $Q_0 = .400$ and $Q_0 = .600$, respectively. From Fig. 4, it appears that Q_0 should be larger than .400, while Fig. 5 suggests that Q_0 should be smaller than .600. Both diagrams indicate, however, that the luminance-corrector improves the rendition of luminance detail. The effect of using a constant Q_0 instead of a ϕ-dependent Q can be detected in both Figs. 4 and 5 as a disproportionality between the improvements in F_{d0} in the green areas and in the magenta areas; e.g., if Q_0 is large enough to bring Q_{d0} to unity near green, F_{d0} will become larger than unity in the neighborhood of magenta.

Other Considerations

The above discussion has been restricted to consideration of the rendition of luminance detail by each of three different systems. In order to retain a proper perspective with respect to judgment of the relative merits of these systems, it is necessary to bear in mind the other characteristics which vary from one system to

another. These include color fidelity, constant-luminance adherence, monochrome noise perceptibility, and compatibility. Attention is therefore called to earlier work by the writer on these aspects of the E_Y' and $E_Y^{1/\gamma}$ systems. In one pair of papers[5] analyses were given for these systems using $\gamma = 2.75$; a later paper[1] presented results of the same analyses for $\gamma = 2.2$. To extend these analyses to the $E_Y^{1/\gamma} - \Delta E_Y^0$ system, the present paper includes in Fig. 6 a set of maps for Luminance Fidelity

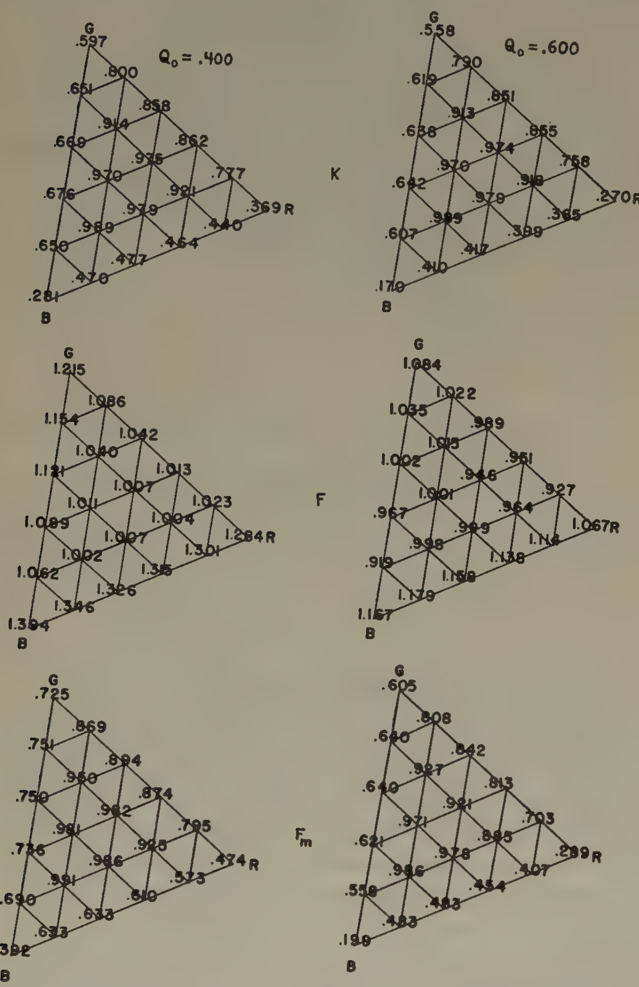

Fig. 6—K, F, and F_m in $E_Y^{1/\gamma} - \Delta E_Y^0$ system for two values of Q_0.

F, Monochrome Luminance Fidelity F_m, and Constant-Luminance Index K, which have been computed for the $E_Y^{1/\gamma} - \Delta E_Y^0$ system both for $Q_0 = .400$ and for $Q_0 = .600$.

It is to be noted that comparison of Fig. 6 with the data in "Colorimetric Analysis of the NTSC Color Television System,"[1] indicates the following properties of the various systems:

Color Fidelity—The E_Y' system yields correct large-area color reproduction. The $E_Y^{1/\gamma}$ system leads to a certain amount of color distortion which, however, has been judged by subjective tests to be negligible except in rare instances. Since values for F in Fig. 6 are larger than unity but not as large as are the corresponding values given in reference 1 for the $E_Y^{1/\gamma}$ system, it follows that color distortion is present in the $E_Y^{1/\gamma} - \Delta E_Y^0$ system but that its magnitude is less than that in the $E_Y^{1/\gamma}$ system.

Monochrome Luminance Fidelity—The $E_Y^{1/\gamma}$ system offers considerably better monochrome luminance fidelity near saturated colors than does the E_Y' system. Values for F_m in Fig. 6 indicate that the luminance-corrector system is much more nearly like the E_Y' system than like the $E_Y^{1/\gamma}$ system in respect to monochrome luminance fidelity. This, of course, is due to the fact that the luminance-corrector converts the low-frequency portion of the monochrome signal approximately to E_Y'. It should be noted at this point that a monochrome receiver will display exaggerated luminance detail when the luminance-corrector system is used, whereas its luminance detail reproduction will be correct both with the E_Y' system and with the $E_Y^{1/\gamma}$ system.

Constant-Luminance Adherence—The $E_Y^{1/\gamma}$ system offers the best constant-luminance adherence, while the E_Y' offers the poorest. The luminance-corrector system performs with an intermediate degree of constant-luminance adherence. Constant-luminance adherence, it will be remembered, is of importance to minimize the susceptibility of a color receiver to variable multipath transmission effects and to spurious signals in the chrominance channel. This seems likely to be of more importance in the long run than completely correct luminance detail rendition.

Conclusions

It has been the principal purpose of this paper to examine the performance of three different forms of the NTSC color television system with respect to the reproduction of luminance detail on a conventional color receiver. The analysis has indicated that the system using a luminance-corrector in the transmitter yields the best luminance detail rendition, but it has been pointed out that the $E_Y^{1/\gamma}$ system also seems to be appreciably better than the E_Y' system in this respect and is superior to both the E_Y' system and the luminance-corrector system in constant-luminance adherence and monochrome luminance fidelity. The E_Y' system seems at this point to be definitely inferior to each of the others.

[5] D. C. Livingston, "Colorimetric Analysis of Gamma-Corrected Shunted Monochrome Simultaneous Color Television Systems," prepared for NTSC Panel 13. Part I, July 1, 1952; Part II, July 3, 1952.

Methods of Verifying Adherence to the NTSC Color Signal Specifications*

ARCH C. LUTHER, JR.†, ASSOCIATE, IRE

Summary—A color-bar test signal is described for verification of the performance of an NTSC color television system. By measurement of the amplitudes and relative phases of a group of bar signals corresponding to saturated primary colors and their complements, it is shown that the basic composition of the multiplexed color signal may be verified. The use of a very simple demodulator for accurate measurement of phase at the 3.58-megacycle subcarrier frequency is also described.

Introduction

THE OSCILLOSCOPE is probably the most important test instrument required for a monochrome television operation. The broadcaster embarking on a color television schedule will find that his oscilloscope has become even more useful, but he will quickly discover the need for additional test equipment which will allow his oscilloscope to present a more definite picture of the color video signal. This equipment is required for measuring the characteristics of the various 3.58-megacycle subcarrier components present in the color signal. Determination of phase at 3.58 megacycles is equally as important as the normal monitoring of video signal amplitude. This paper will describe the measurement techniques for specifying the characteristics of the color video signal.

The Color Signal Specifications

The color signal may be considered as the sum of two components, the monochrome signal E_W, and the chrominance signal E_C. E_W is an ordinary monochrome video signal whose value is proportional in a certain way to the three color video signals from the camera. E_C, on the other hand, is a two-phase modulated subcarrier component at 3.58 megacycles. It may be further subdivided into its two quadrature components E_I and E_Q. In addition, a burst of the same frequency as E_C is transmitted following each horizontal synchronizing pulse for the purpose of synchronizing a subcarrier source at the receiver.

Composite video voltage E_m may be expressed by:

$$E_m = E_W + E_C$$

$$E_M = E_W + E_I \cos(\omega t + 33°) + E_Q \sin(\omega t + 33°). \quad (1)$$

The phase reference in (1) is taken as (burst+180 degrees). The 33 degrees indicate that the Q signal leads the phase reference by 33 degrees. The I signal leads the Q signal by 90 degrees. This may be seen more clearly in the vector diagram of Fig. 1.

The amplitudes E_W, E_I, and E_Q are related to the red, green, and blue video voltages E_R, E_G, and E_B by the relations below,[1] commonly referred to as the matrix equations.

$$E_W = 0.30E_R + 0.59E_G + 0.11E_B \quad (2)$$

$$E_I = 0.60E_R - 0.28E_G - 0.32E_B \quad (3)$$

$$E_Q = 0.21E_R - 0.52E_G + 0.31E_B. \quad (4)$$

It can be seen from (2), (3), and (4) that there are nine coefficients which must be checked for signal verification. In addition, the phase relationship between I, Q, and burst in Fig. 1 must be measured.

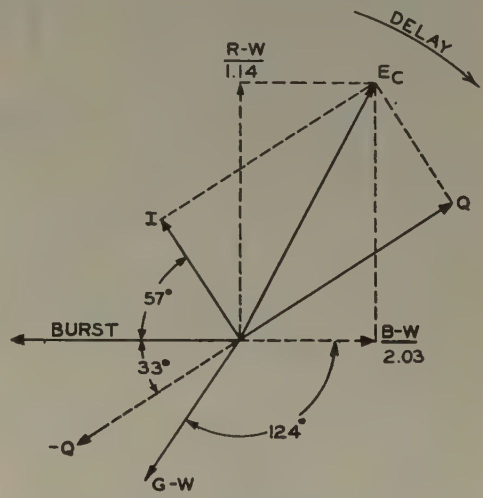

Fig. 1—Vector diagram showing relationship of burst, I, Q, $R-W$, and $B-W$ for a particular chrominance E_C.

The Color-Bar Test Pattern

It is necessary, then, to provide a signal which will generate enough different conditions in the color system to check all of the above mentioned variables. It would be convenient for this test signal to have some physical significance in terms of real colors, and the signal should also be useful for checking other parts of the system such as monitors and receivers. For these reasons the color-bar test pattern has been developed. This pattern provides a sequence of vertical bars in the picture area showing the saturated primaries, their complements, and white. For testing with such a signal, the response of the color system to the test signal must be found.

The color-bar test signal generator provides a sequence of pulses to the red, green, and blue signal input

* Decimal classification: R583. Original manuscript received by the Institute, October 22, 1953.

† RCA, Victor Div., Camden, N. J.

[1] Petition of Radio Corporation of America and National Broadcasting Company, Inc., for Approval of Color Standards for the RCA Color Television System, p. 139, presented to the FCC June 25, 1953.

terminals of the encoding apparatus which provides all possible combinations of the saturated primaries. Fig. 2 shows one possible set of wave forms for a color bar pattern and a sketch of its appearance on a color monitor.

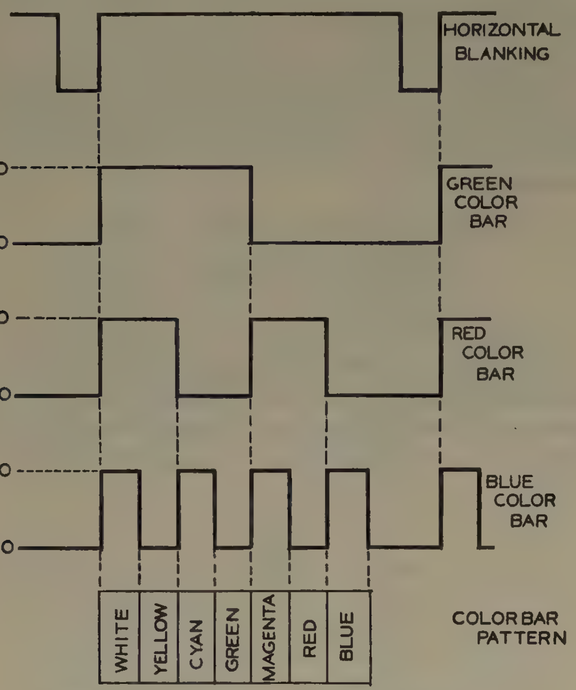

Fig. 2—Wave forms of color-bar pattern.

The amplitudes of the subcarrier and monochrome components for the color bars may be calculated by substituting the appropriate values of the red, green, and blue input signals into (2), (3), and (4). For example, for a yellow bar:

$$E_R = 1.0 \qquad E_G = 1.0 \qquad E_B = 0$$

$$E_W = 0.30 + 0.59 = 0.89$$

$$E_I = 0.60 - 0.28 = 0.32$$

$$E_Q = 0.21 - 0.52 = -0.31.$$

The peak amplitude of the yellow chrominance component will then be:

$$E_C = \sqrt{E_I^2 + E_Q^2} = 0.44.$$

Combining the monochrome and chrominance signals for the maximum and minimum peaks of the yellow video signal:

$$E_m \max = 0.89 + 0.44 = 1.33$$

$$E_m \min = 0.89 - 0.44 = 0.45.$$

The phase angle by which the resultant chrominance signal is delayed with respect to the burst may be obtained from:

$$\theta = 147° - \tan^{-1} \frac{E_I}{E_Q}. \tag{5}$$

Where the proper quadrant must be chosen from the signs of E_I and E_Q. For the yellow color bar:

$$\theta = 147° - \tan^{-1} \frac{1.32}{-.30} = 147° - 134° = 13°.$$

Similar calculations have been carried out for the other color bars; the values are tabulated in Table I. Fig. 3(a) shows the monochrome component of the color-bar signal; Fig. 3(b) shows the chrominance component; and Fig. 3(c) is the composite wave form developed by adding the signals of (a) and (b). Practical color-bar test pattern wave forms should look like these wave forms except that the color bars may take a different sequence.

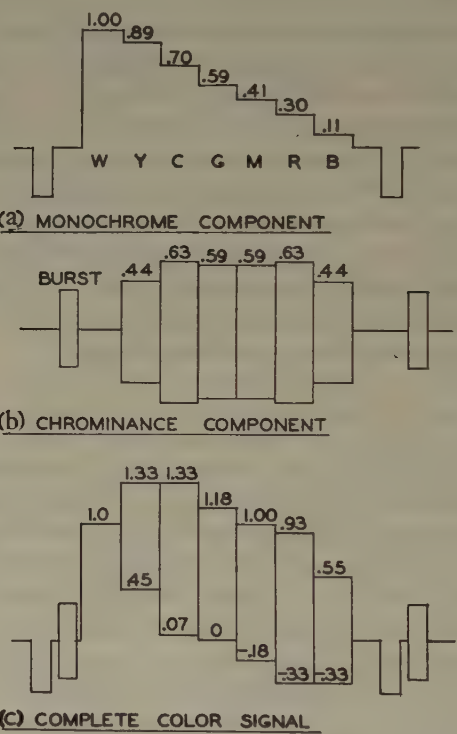

Fig. 3—NTSC signals for color-bar test pattern.

Oscilloscope Measurements

The wave forms of Fig. 3 may be observed on an oscilloscope by the use of a high-pass, low-pass filter to separate the monochrome and chrominance compo-

TABLE I

Color	E_R	E_G	E_B	E_W	E_I	E_Q	E_C	(ϑ)*
White	1	1	1	1.00	0	0	0	—
Yellow	1	1	0	0.89	0.32	−0.31	0.44	13°
Cyan	0	1	1	0.70	−0.60	−0.21	0.63	257°
Green	0	1	0	0.59	−0.28	−0.52	0.59	299°
Magenta	1	0	1	0.41	0.28	0.52	0.59	119°
Red	1	0	0	0.30	0.6	0.21	0.63	77°
Blue	0	0	1	0.11	−0.32	0.31	0.44	193°

* Given as delay from burst.

nents. Such a filter designed to operate from a 75-ohm line is shown in Fig. 4. This has cut-off frequencies at approximately 1 megacycle on both high-pass and low-pass positions. Actual wave forms of a typical color-bar signal are shown elsewhere in this issue.[2] An important characteristic of the oscilloscope, particularly for measurement of the pattern in Fig. 3(c), is the accuracy of the high-frequency response. It is essential for the oscilloscope to have closely the same gain at 3.58 mc as at low frequencies if the ratio of chrominance to monochrome information is to be accurately displayed.

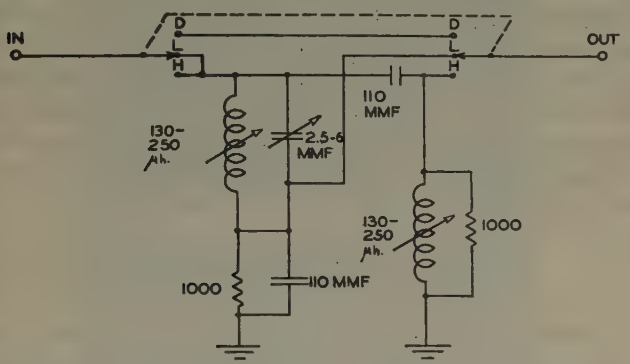

Fig. 4—High-pass low-pass filter for input to oscilloscope.

An important oscilloscope measurement which is not directly related to the signal equations is that of carrier balance. The modulators for the Q and I subcarrier components must be set up for the condition that zero input produces zero output. Therefore, at any point where the red, blue, and green video signals are simultaneously zero (black), there should be no subcarrier present in the color signal. A convenient point to check for carrier unbalance is during the horizontal blanking interval, where all the inputs will be at black. Carrier balance is indicated by the complete lack of 3.58-megacycle feedthrough during this time.

An additional test is that of white balance. It can be seen from (3) and (4) that E_I and E_Q go to zero for white ($E_R = E_G = E_B = 1$). This condition again implies zero input to the I and Q modulators and consequently no subcarrier should appear on the white pulse of the color-bar signal.

Measurement of Phase

The measurement of relative amplitude of the different color bars as previously described is capable of representing the major characteristics of the signal. However, a complete test is not possible without a measurement of phase. The need for such phase measurements has prompted the development of specialized equipment for phase test at 3.58 mc. One such device is the color-signal analyzer which is based on a simple synchronous demodulator of the same type as is used in color receivers. Fig. 5 is a simplified diagram of the color-signal analyzer.

The chrominance information of the color signal is separated by a high-pass filter and fed to the first grid of a 6AS6 modulator pentode. The suppressor grid of the 6AS6 receives a continuous wave subcarrier reference signal which is either obtained from the color-signal generating equipment or may be generated from the synchronizing burst by a burst-controlled oscillator. Provision is made for shifting the phase of the reference subcarrier through 360 degrees with an uncalibrated phase shifter as well as shifting it by an accurately calibrated amount with the phase standard.

The output of the demodulator is observed with an oscilloscope through a low-pass filter which removes all frequencies above about one megacycle. This type of demodulation has the property that the low-frequency output (below subcarrier frequency) is proportional to $AB \cos \theta$ where A and B are the amplitudes of the subcarrier on the two grids and θ is the phase angle between them. The significant point is that this factor goes to zero when the phase angle is ± 90 degrees. With the color-bar signal going into the color-signal analyzer it will be possible to obtain a null on each color bar, when the phase of the reference subcarrier differs from the appropriate color bar by exactly 90 degrees. Two nulls on each bar will be obtained for each 360 degrees of phase shifting, corresponding to the phase difference being plus or minus 90 degrees.

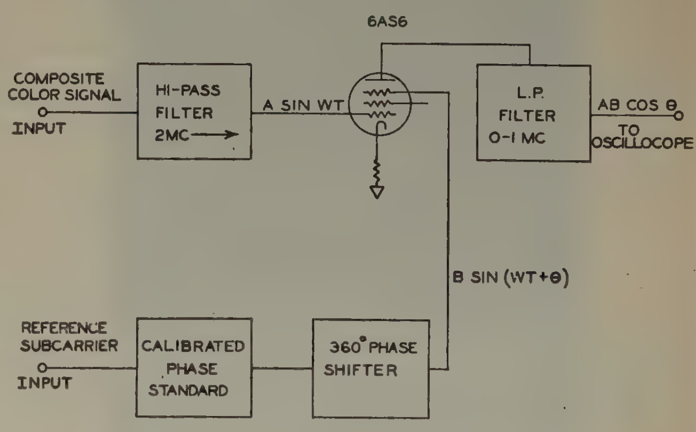

Fig. 5—Color-signal analyzer.

In operating the color signal analyzer it is necessary to first establish a reference with respect to some part of the signal. An obvious reference point is the synchronizing burst. With the phase standard set to 0, a null is obtained on the burst by variation of the 360-degree phase shifter. At this point the demodulator will be operating at exactly 90 degrees to the burst. Then if by variation of the phase shift of the phase standard, a null is obtained for some other component of the signal, the phase difference between the burst and this signal component may be read directly from the dials of the phase standard. On the color-bar signal, since the pri-

[2] A. H. Turner and E. E. Gloystein, "Multiplexing color signals in accordance with NTSC signal specifications," Proc. I.R.E., pp. 204–212; this issue.

maries and their respective complements produce chrominance signals having exactly opposite phase, two nulls should always occur simultaneously, one on a primary color bar, and the other on the respective complementary color bar. Since the two bars actually differ in phase by 180 degrees, the two nulls will approach from different directions, but the pulses from the color-signal analyzer should both cross the baseline at the same phase setting.

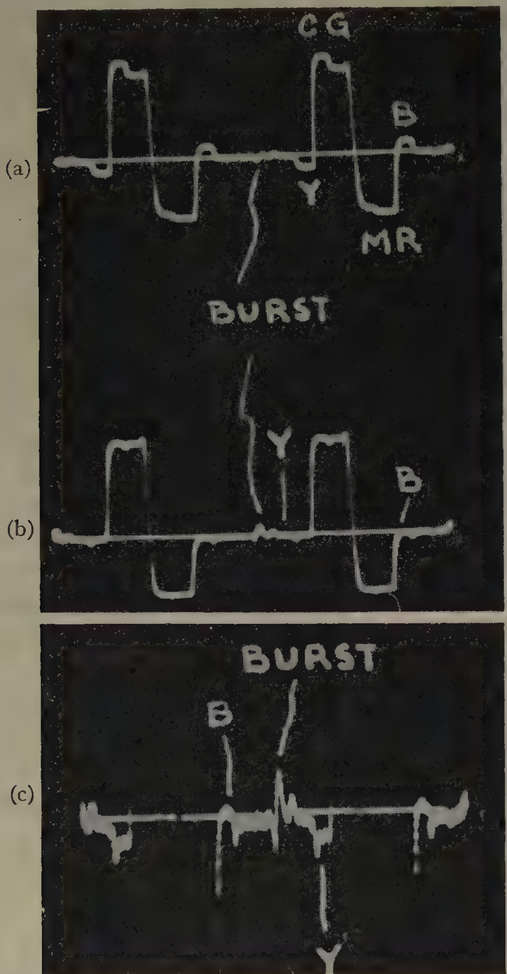

Fig. 6—Output wave forms of color-signal analyzer. (a) Color bar signal of Fig. 3 for null on burst. (b) Same as (a) with phase shifted to null on blue and yellow bars. (c) Same as (b) except phase is further shifted by 2 degrees, with expanded vertical deflection of oscilloscope.

Fig. 6 shows actual wave forms from a color-signal analyzer for the previously mentioned conditions. Fig. 6(a) shows the color-signal analyzer output for a null on the burst. Fig. 6(b) shows the same wave form when the phase has been shifted for nulls on the blue and yellow bars. Note that the burst is no longer cancelled out. Fig. 6(c) is the same as (b) except that the phase has been shifted by 2 degrees, showing that the outputs on the yellow and blue bars change in opposite directions. It can be seen that the readability of phase differences with this instrument is very good; the limiting accuracy is considerably better than 1 degree, depending primarily on the calibration of the standard phase shifter.

Phase measurements may be made for each of the color bars in this way, to provide a check against the phases of Table I. The phase values of Table I have been calculated with respect to the synchronizing burst, on the basis of starting with the burst and going in the direction of increasing delay (corresponds to increasing phase shift of standard phase shifter, or clockwise on Fig. 1).

The values given are the actual phase differences between each bar and the burst. It should be apparent that the color-signal analyzer will give a null when the phase is 180 degrees different from these values. Thus, starting with the burst, a 13-degree delay will null on yellow and blue, increasing the phase shift to 77 degrees will null red and cyan, and at 119 degrees magenta and green will null. Furthermore, it does not matter whether the procedure starts with the burst itself, or 180 degrees out of phase, the relative phase to the null of each color bar will be the same.

Other Test Possibilities

A simple addition to the color-signal analyzer can make it possible to reconstruct the red, blue, and green color signals. This is a very useful way to check the over-all characteristics of the signal, since the receiver is required to demodulate the color signal in the same manner. The color-signal analyzer is operated to produce a null on the burst. This means that the demodulator is actually operating at 90 degrees to the burst, or along the $R-W$ axis as can be seen in Fig. 1. The output of the demodulator will then be $E_R - E_W$, and if this is added to the appropriate amount of the monochrome signal E_W, the result should be just the red signal E_R shown by Fig. 2.

In practice, an adder is built into the output of the color-signal analyzer so that E_W separated from the incoming signal via a low-pass filter can be added to the output of the demodulator. A level adjustment in the E_W channel provides an adjustment for the proper amount of monochrome addition, at which point the contributions of the blue and green signals in the output should be simultaneously cancelled as shown by Fig. 7. If this is not the case it is an indication that there are errors in the signal which will produce the same type of color cross talk in a receiver as observed in this test. Thus the over-all usefulness of the color signal can be evaluated.

If the phase of the color-signal analyzer is now shifted by 90 degrees, demodulation will take place along the axis of the burst, or $B-W$ axis. Addition of E_W will then allow reconstruction of the blue signal. It should be noted that for both these tests, if demodulation occurs at 180 degrees to the proper phase, the output from the demodulator will be inverted and cancellation of the other colors will be impossible. In such a case it is only necessary to shift the phase of the color-signal analyzer by 180 degrees.

(a)

(b)

(c)

Fig. 7—Output wave forms of color-signal analyzer for signal reconstruction. (a) Color bar signal demodulation along $R-W$ axis. No E_W added. (b) Same as (a), but with proper amount of E_W added for complete reconstruction of E_R. Compare with Fig. 2. (c) E_w required by (b).

In order to provide a similar test for the green video signal, it is necessary to delay the color-signal analyzer subcarrier another 124 degrees from the $B-W$ test. Then the demodulation should be such that E_G-E_W is produced, and addition of the proper E_W signal will recover E_G. The reconstruction method provides a complete check of the color signal with three simple checks; in addition it is readily evident what type of difficulties any signal fault would cause in a standard receiver.

Direct Measurements of I and Q Phase

Generation of the color signal is ordinarily accomplished in the colorplexer by deriving the Q and I and burst subcarrier components and the monochrome component separately and combining them to get the complete color signal. Consequently in testing the outputs of such equipment, measurements of the amplitude and phase of the color bars does not provide a direct indication of what part of the colorplexer is at fault when an error is discovered. In order to obtain more useful information it is desirable to be able to directly measure the relative phases of I, Q, and burst.

Since I and Q cannot occur separately in a color-bar pattern, two extra pulses are added to the pattern. These pulses are connected to the colorplexer in such a

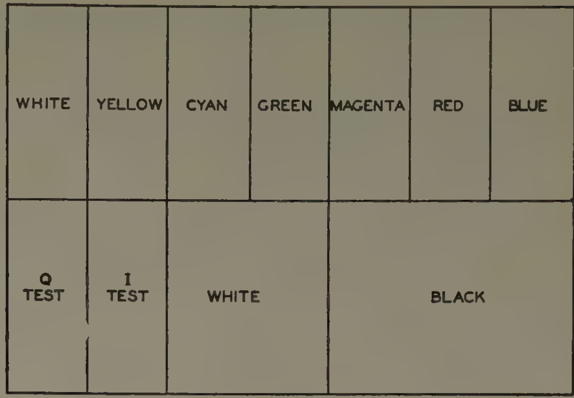

Fig. 8—Color-bar pattern.

way that they directly operate only the I and Q modulators. The color-bar pattern is electronically switched so that color bars remain at the top of the raster but the two test pulses and a second white bar appear at the bottom. The pattern on a monitor produced by this type of color-bar signal is shown in Fig. 8. The two test

(a)

(b)

(c)

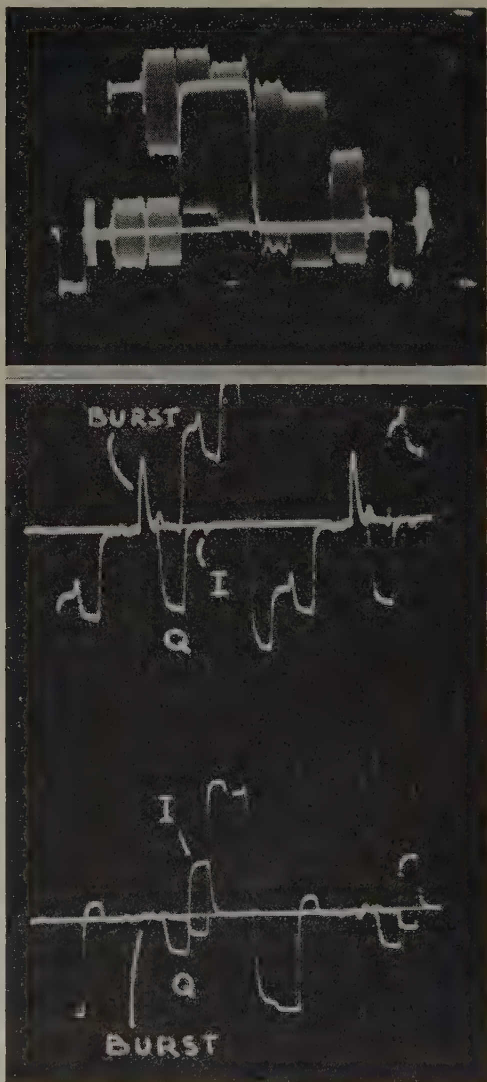

Fig. 9—(a) Color-bar signal of Fig. 8. (b) Output of color-signal analyzer for input shown by (a). Phase adjusted for null on I test pulse. (c) Same as (b) except phase shifted to null on burst.

pulses produce two bursts, one having the phase of I and one having the phase of Q. Their amplitude is not important, but they should be made no larger than the burst so that they produce no negative pulses greater than sync in any demodulated color channel.

The color-bar signal with the I and Q test pulses appears as in Fig. 9(a). The first step in checking I and Q phase is to obtain a null on the Q test pulse with the 360-degree phase shifter. Once this null has been obtained with the delay standard set to zero, 33 degrees is switched in and the burst should null. An additional 57-degree phase shift, making a total of 90 degrees, should then produce a null for the I test pulse. Fig. 9(b) and (c) show the output of the color-signal analyzer for these test conditions. This procedure allows a quick check of all the phases which are involved in a colorplexer. If the amplitudes have been properly set, the phases of the color bars should come out correctly by virtue of the matrix equations.

Conclusion

A complete specification of the color video signal requires accurate measurement of signal levels at frequencies to 3.58 megacycles, and phase measurement at 3.58 megacycles. It has been shown that a good wide-band oscilloscope is sufficient for all amplitude measurements, and the phase measurements can be handled by a simple device containing a synchronous demodulator of the same type which is used by color receivers for demodulation of the color signal. Measurements can be made with an accuracy exceeding the NTSC requirements by an order of magnitude so that the methods are useful not only for signal verification, but can be used for matching of color video signals within the studio. The accuracy requirements here are much more stringent if cameras are to be switched without hue and color balance shifts.

Apart from direct measurements on the color signal itself, it should be clear that the color-signal analyzer can be used to measure the phase of any type of 3.58-megacycle signal. In this connection, it is used extensively for phase intermodulation measurements on amplifiers and transmitters in the color system.[3]

Acknowledgment

The writer wishes to express his appreciation of the capable assistance and suggestions of J. W. Wentworth and E. E. Gloystein in the preparation of this paper.

[3] J. A. Bauer, "A versatile approach to measurement of amplitude distortion in color TV," Proc. I.R.E., this issue, pp. 240–246.

A Versatile Approach to the Measurement of Amplitude Distortion in Color Television*

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***Summary*—The reasons for making gamma corrections are briefly reviewed. The need for maintaining linearity throughout the transmission system is emphasized. An instrument is described which enables the user to more conveniently obtain an expression for the degree of nonlinearity and therefore exercise greater control over it. This instrument is based on early proposals made by the I.R.E. Committee on Video Techniques. Wider use of such instruments should prove beneficial to the industry and result in further refinements.**

Introduction

INCREASING FAMILIARITY with the recommended NTSC signal specifications for color television soon brings the realization that little, if anything, has been changed in the basic monochrome television system requirements except that operating tolerances have become more closely controlled. Some improvements in the quality of black-and-white transmissions should then become noticeable along with the added ability to transmit color. To better understand this our attention ought to be directed to several pertinent characteristics of the system which seem to have a definite bearing on this matter.

For example, unimpaired transmission of the subcarrier will now require that the amplitude versus frequency curve be made more sufficiently flat throughout the system. For this reason instruments such as the BW-5A Television Sideband Response Analyzer have been developed.[1]

The phase vs. frequency curve also merits greater consideration. Because of this, equalizers will be found more freely applied at the transmitter and to some degree in the receivers. To more effectively control this, instruments such as the envelope delay sweep are beginning to make their appearance in the market.

Particular regard will also be given to gamma values or transfer characteristics. While this is not entirely new to the monochrome system it now becomes essential that suitable corrections be made from both sending and receiving point considerations. In addition, assurance is required that such gamma values, once correctly estab-

* Decimal classification: R583. Original manuscript received by the Institute, October 26, 1953.
† RCA Victor Division, Camden, N. J.

[1] J. A. Bauer and F. E. Talmage, "The RCA BW-5A television sideband response analyzer," *Broadcast News*, pp. 32–39; July/August, 1953.

lished, be transmitted over a completely linear system in order to preserve them.

Need for Linearity

Our objective here is to introduce an instrument having features which have proved useful and valuable in establishing and maintaining the last named characteristic of the color television system. The linearity checker should become as important a tool for television as distortion meters or analyzers have proved in the past for sound transmission systems. The need for such an instrument as the linearity checker becomes evident if we review the following considerations:

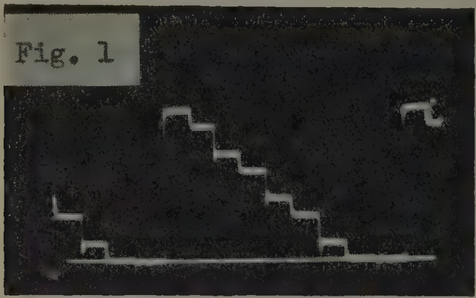

Fig. 1—Color-bar generator signal showing luminance components only.

A. When we establish and preserve gamma values we maintain not only the brightness values in the gray scale as in monochrome practice but also the brightness or luminance and chrominance values associated with each color hue, hence its saturation. At the risk of some repetition, it would be well to look again at a line of composite-color video signal obtained with the aid of a color-bar generator. Fig. 1 shows only the luminance components associated with each color. This is in accordance with Table I. It should be immediately evident that any stretching or compression will disturb these values and therefore change the level of white mixed with each color or its saturation.

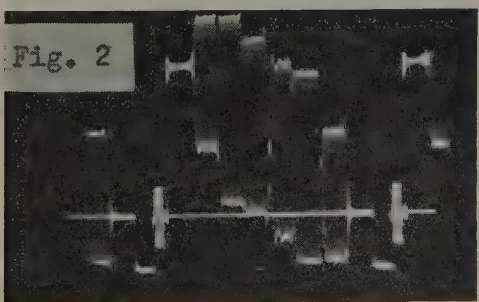

Fig. 2—Both luminance and chrominance components shown.

Fig. 2 shows the chrominance superimposed on the luminance signal. Again from Table I, definite values of chrominance signal will be found with a particular phase angle associated with each color. It should be realized that if any clipping of the chrominance signal occurs this will in all probability be accompanied by a change in its phase angle. Therefore the hue of the color will be changed.

B. Even where gross errors in transmission such as clipping are avoided it becomes important that we avoid phase intermodulation, i.e. change in subcarrier phase with changes in luminance level. As we have seen in *A* above, the subcarrier phase must be maintained in order to preserve the hue of a color. Nonlinearity is frequently, but not always, accompanied by phase intermodulation. All components in the system should exhibit excellent performance in this respect. While nine degrees has been suggested as an over-all limit for the entire color TV system with possibly three degrees of this apportioned to the transmitter, it is easy to see that an originating studio should strive for something in the order of less than one degree for its over-all limit. When we think of the individual components of a large network then each should account for no more than something in the order of 0.1 or even 0.01 degree!

C. Any nonlinear distortion in the white region of the recommended NTSC signal specifications may result in both distortion effects due to amplitude and phase changes together, as in *A* and *B* above.

D. Nonlinearity near the black region will result in stretching or compression of the sync pulses, with possibly a change in the phase of the subcarrier reference burst if accompanied by any clipping. This last would be most serious since it changes the phase relation between all chrominance and reference-burst signals.

TABLE I
Luminance and Chrominance Values

Color	P/P luminance or Y Signal	Pk. Chrominance or Combined I&Q Signal	Angle from Burst
White	1.00	0	0
Yellow	0.89	0.45	12.4°
Cyan	0.70	0.63	256.0°
Green	0.59	0.59	299.0°
Magenta	0.41	0.59	119.0°
Red	0.30	0.63	76.5°
Blue	0.11	0.45	192.0°

Linearity Checker

The linearity checker shown in Fig. 3 will be more quickly understood if we study the wave form delivered by the instrument. Fig. 4(a) shows this signal as set up for some typical usage. Blanking and sync pulses are evident, together with nine lines of white signal followed by a staircase of ten steps every tenth line. Fig. 4(b) shows the staircase expanded. A pair of controls is provided for adjusting the uniformity of the steps.

Fig. 5(a) again shows the expanded staircase but with a superimposed sine wave signal of 3.58 mc which will be recognized as the color subcarrier frequency. The appearance of this apparently gave rise to the term "saw-step-sine wave" which has appeared from time to time in IRE sub-committee discussions on linearity measurements. For added flexibility a frequency of 1 mc may be

Fig. 3—Front panel view of the linearity checker.

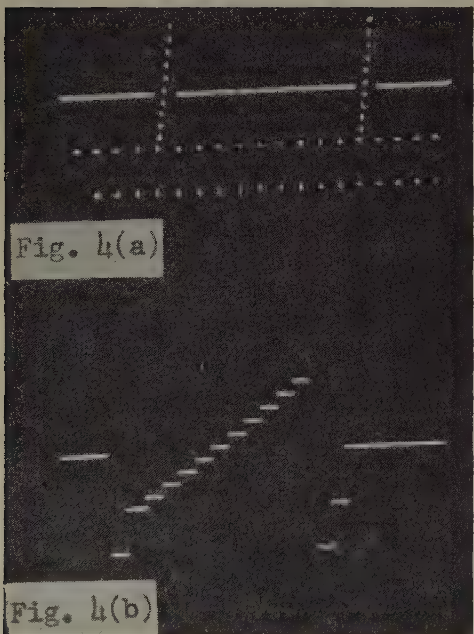

Fig. 4(a)—Signal output for typical use; (b) staircase expanded.

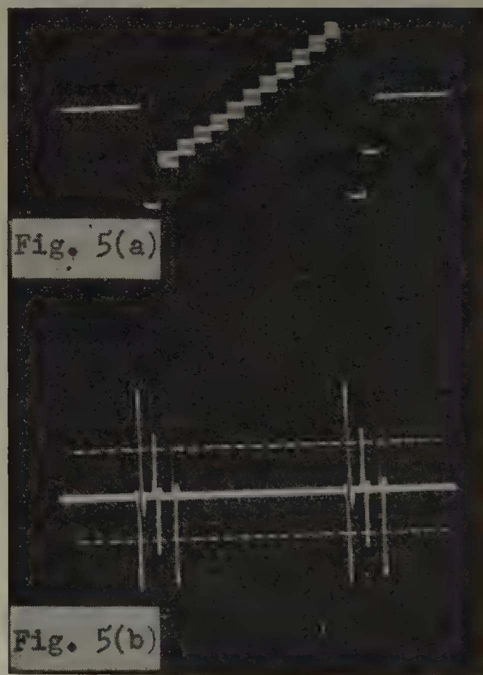

Fig. 5(a)—Staircase with cw sub-carrier superimposed. (b) Signal of 6(a) through high pass filter.

superimposed on the staircase instead of 3.58 mc. Any externally supplied sine wave may be substituted as well. Provision is made for controlling the amplitude of this superimposed signal. Upon passing this signal through a simple filter with provision for passing either high or low frequencies, the staircase can be removed with the filter in high position. Blocks of cw subcarrier having uniform height are then seen as in Fig. 5(b). This filter is supplied as an accessory with the linearity checker and a schematic is shown in Fig. 6.

With an appropriate setting of the horizontal sweep on the oscilloscope a block of signals such as shown in Fig. 7(a) will be observed at the input to some nonlinear device. This may be compared with the output signal

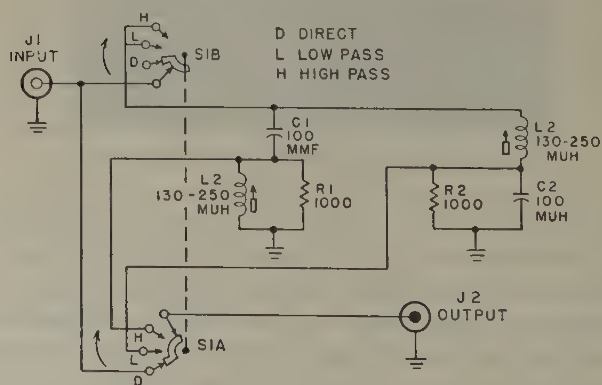

Fig. 6—Schematic of the "Hi-Lo" filter.

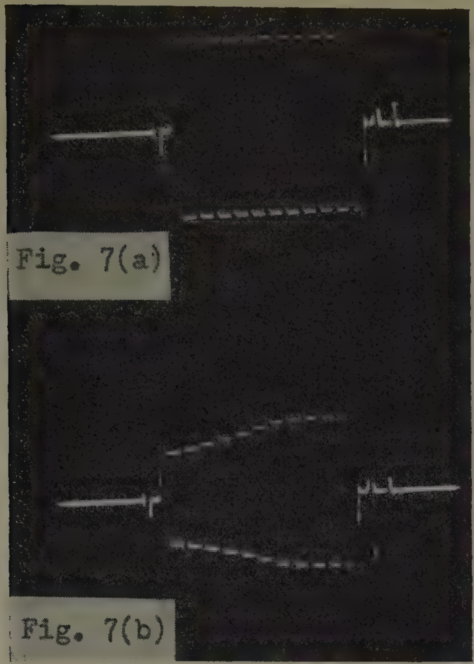

Fig. 7(a)—Input to nonlinear device (high pass). (b) Output from nonlinear device (high pass).

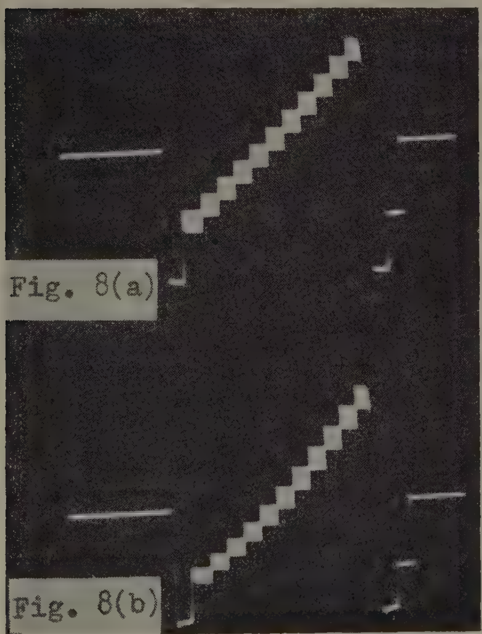

Fig. 8(a)—Input to nonlinear device (direct). (b) Output from nonlinear device (direct).

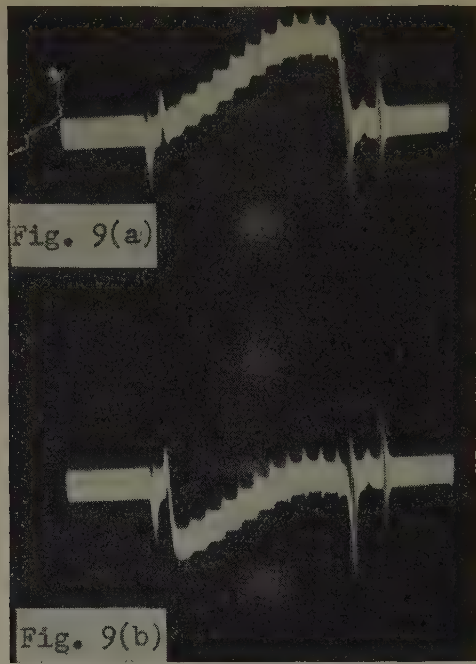

Fig. 9(a)—Zero null reference established at leading edge of wave train. (b) 30 degree phase shift introduced to zero null trailing edge.

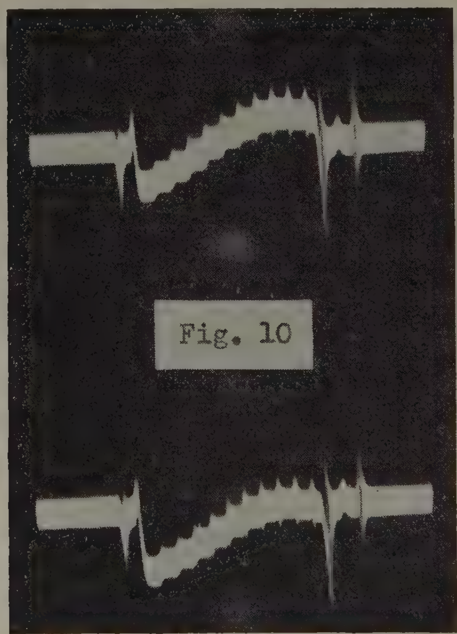

Fig. 10—Insertion of only 1 degree by signal analyzer.

in Fig. 7(b) showing evidence of the compression in this device.

While Figs. 5(b), 7(a) and 7(b) are viewed with the filter in the high-pass position, Fig. 8(a) and 7(b) show the input and the output signals to the device with the filter in the direct position. Although the nonlinearity is also visible in Fig. 8 its degree is not nearly as apparent as when viewed through the high-pass position of the filter as in Fig. 7. We can also use Fig. 7 readily to obtain an expression for the degree of nonlinearity by using a simple formula:

$$\text{Compression} = \left(1 - \frac{b}{a}\right) \times 100 \text{ per cent}$$

where a = height of uniform (linear) portion of wave train, and b = height of smallest block of sine wave train.

In this example the compression appears to be approximately

$$\left(1 - \frac{17/64}{26.5/64}\right) \times 100 \text{ per cent} = 36 \text{ per cent.}$$

Stretching at either end of the wave train is similarly calculated.

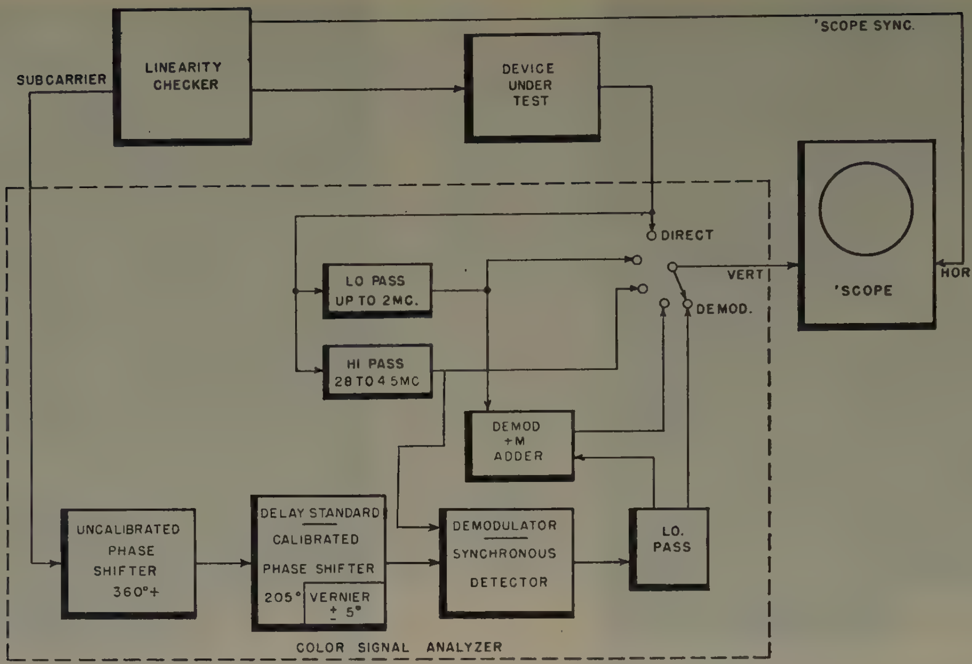

Fig. 11—Arrangement for checking phase intermodulation.

Use with Color Signal Analyzer

As we have suggested before, the linearity checker is also useful in determining the phase intermodulation in any device. However, a measurement of this kind must be made in conjunction with a color signal analyzer,[2] another instrument developed for color television. The photos shown in Fig. 9(a) and (b) were taken with the help of such an analyzer. Fig. 9(a) shows a zero null reference established at the leading edge (black portion) of the wave train. The insertion of three degrees shift in the signal analyzer brings our zero null reference to the trailing edge (white portion). The test shows that three degrees of phase intermodulation was introduced by the same nonlinear device under test as used in the preceding photos. Figs. 10(a) and (b) show the insertion of just one degree of phase shift to demonstrate the sensitivity of this instrument.

These photographs were made possible by connecting the linearity checker, signal analyzer, device under test, and oscilloscope as shown in the block diagram of Fig. 11. This diagram shows that the signal analyzer is principally composed of an uncalibrated phase shifter, the delay standard or calibrated phase shifter, and a demodulator. The demodulator is of the synchronous detector type and of the same kind used for I and Q demodulators in current models of color television receivers. Its useful characteristic here is that there is a sharp null zero output of the demodulator when the subcarrier signal is exactly ninety degrees out of phase with another incoming signal. By initially adjusting the subcarrier phase for a zero null output at the leading or black end of the wave train with the uncalibrated phase shifter we obtained Fig. 9(a). By then inserting three degrees phase shift with the delay standard the trailing or white end of the wave train was brought to zero as in Fig. 9(b).

[2] A. C. Luther, "Methods of verifying adherence to the NTSC color signal specifications," Proc. I.R.E., pp. 235–240; this issue.

Operation and Features of the Linearity Checker

A. Master Circuits

Referring to the block diagram of Fig. 12, the free-running master multivibrator V5 provides a symmetrical square-wave output of approximately 15,750 cps. If desired, a switch is provided so that this circuit may be changed to an amplifier which then accepts horizontal-drive pulses. All the following circuits are then driven from the amplified horizontal-drive signal.

The output separates in two branches. One of these is differentiated and the negative pulse fed to V7A and V10A. The width of this pulse is controlled with a potentiometer. The other branch is differentiated and fed to V6A. The width of this pulse is controllable in the same manner.

B. Gating Circuits

The negative pulse fed to the grid of V7A appears negative across the common cathode-resistor of V7A and the blocking oscillator V7B. This pulse locks the blocking oscillator to one-tenth the line frequency. The output of the blocking oscillator is differentiated and fed to the step and gating pulse multivibrator. The width of the negative going output pulse of the blocking oscillator is determined by a potentiometer. Simultaneously the delay of the positive pulse for locking the step and blanking gate multivibrator is also controlled. As will be seen, this also determines the start of the leading

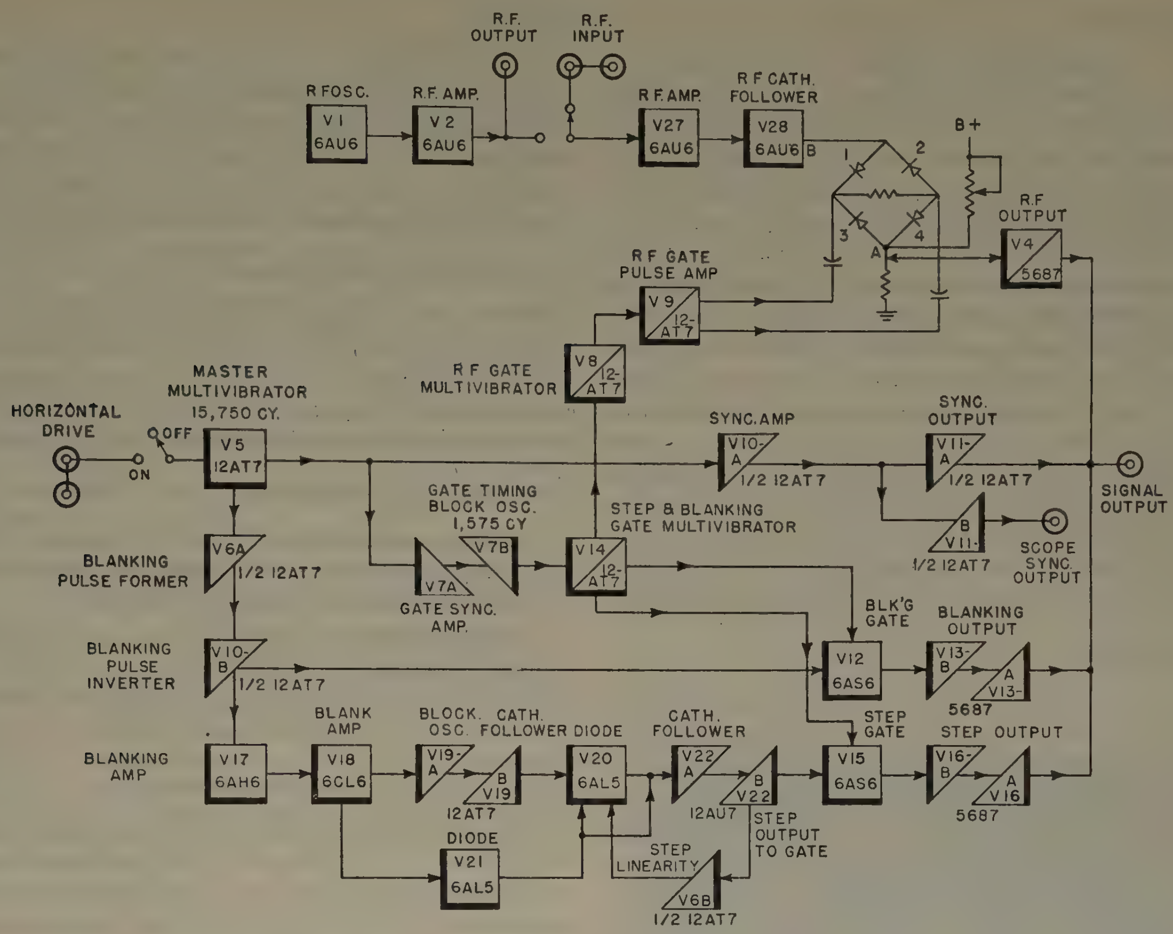

Fig. 12—Block diagram of linearity checker.

edge of the pulse for gating on the rf signal. This delay is approximately the width of sync since the rf must start immediately following sync.

The output of the blocking oscillator feeds through a series-parallel diode circuit which feeds the positive going pulse to V14 for triggering the step and blanking gate one-shot multivibrator. A positive pulse from this multivibrator is fed to V15 for gating on the step signal and a coincident negative pulse is fed to V12 for gating off the white signal while the step is on. The width of this pulse is adjustable. One output of this multivibrator is also differentiated and fed through a series-parallel diode circuit which feeds positive pulse on leading edge to V8 for triggering one-shot rf gate multivibrator.

A positive pulse from V8 is fed to V9A. The negative pulse from the plate of V9A feeds a push-pull tube whose output operates a four-diode gate circuit.

This gate circuit operates in the following manner: During the period when the pulse is off the diodes are biased by the charge on the condensers with such an amplitude and polarity that they remain open. When the pulses are applied the diodes are biased to zero. It is then that the positive going portion of the sine wave at the output of V28 passes through diode no. 1, *R*, and diode no. 3, appearing across the output resistor. The negative portion of the sine wave feeds through diode no. 2, *R*, and diode no. 4. The combined signal then appears at point *A*. The variable resistor connected from point *A* to *B*+ is adjusted so that the same dc voltage is maintained at *A* as at point *B*. This prevents any dc current from passing from point *B* to *A* when the diodes are closed, and thus changing the ac zero axis during the pulse "on" periods as compared with the "off" periods.

C. Blanking Circuit

The pulse from the master multivibrator V5 is formed by V6A and inverted by V10B. This pulse is then gated off, during every tenth line, in V12 by the gating pulse from V14. The output of V12 is fed to the series amplifier and the output of this tube appears across the 75-ohm termination in parallel with the 75-ohm output line. The blanking pulse from V10B is also fed to V17 for operating the step generator.

D. Sync Circuits

The triangular pulse at the grid of V10A is amplified and formed into a square wave appearing on the plate and fed to the sync output tube VIIA and 'scope sync output V11B. The output of these tubes appears on their respective jacks: signal output and 'scope sync. The 'scope output is high impedance.

E. Step Generator

The blanking pulse from V10B is amplified by V17 and V18. A pulse off the cathode of V18 is used to sync the blocking oscillator V19A at approximately 150 kc. The output of the blocking oscillator is coupled to a cathode follower then in turn passes through diode V20A and charges the 470 MMF capacitor to a higher value with each pulse. As there is no discharge path for C57, a step signal appears across C57. A negative pulse from V18 closes the diode during blanking, thus permitting C57 to discharge through the diode and R101 to ground. The cycle then repeats. The output of the step generator then appears across the cathode follower V22A. V22B, V6B, and half of the diode V20 are a part of a feedback circuit to provide linearity adjustments for the step signal. The output of the step generator is fed to the gating tube V15 and gated through V15 (at every tenth line) by the positive pulse from V14. V16 is a series amplifier used for output of the step signal.

F. RF Circuits

V1 is a crystal-controlled oscillator providing a choice of 3.579545 or 1 mc crystals. The output of the oscillator is amplified by V2 and V27 and then coupled to V28, a cathode follower feeding the four-diode gate circuit. The output appearing at point *A* is coupled to the grid of V4B during the pulse "on" periods. V4 is a series amplifier the output of which is coupled to J6.

A continuous rf signal of two volts peak to peak is fed to the rf output jack for feeding a 75-ohm line. A switch is provided at the grid of V27 for selecting the internal rf signals or an external signal between 0.1 and 5 mc. Two volts of external signal are required.

G. Filter

This filter has a three-position switch: direct, low, and high. In the low-pass position the color subcarrier frequency is filtered out leaving the step, blanking, and sync signals. In the high-pass position only the color subcarrier appears across the output with small pips coincident with the various step intervals.

H. Input-Signal Requirements

While the unit is self-contained and actually requires no input signals, RMA horizontal drive signal of 4V P/P may be used to control the input circuits as described under *A* above. External sine-wave signal may also be superimposed optionally as mentioned in *G*.

I. Output-Signal Summary

1. CRO sync signal of 15 v at 15,750 cps.
2. 2 Volts of 1 mc or 3.579545 mc across 75 ohms. These signals are crystal controlled.
3. Adjustable white signal up to 1 v with blanking and sync at 15,750 cps.
4. Saw-step-sine wave every tenth line. The amplitude of the staircase is adjustable.

Acknowledgement

The experimental model of this unit was first constructed by E. E. Gloystein. J. K. Malinoski developed the product design and furnished much valuable information. A. C. Luther assisted with photographs and suggestions. The basic method of using step signals or sawtooth signals with superimposed sine wave for making linearity measurements was originally proposed in the I.R.E. Committee on Video Techniques.

Test Instruments for Color Television*

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Summary—The development of color television has produced some "growing pains" in television system operation. To radiate a satisfactory color TV signal, routine maintenance must include the measurement and adjustment of some characteristics not ordinarily considered for monochrome television. In other cases the accuracy of operation must be considerably better than in the past. This paper describes several test instruments developed to simplify some of these measurements.

The first instrument described produces a frequency response test signal. The signal contains the elements necessary for normal operation of clamp circuits so that a rapid check can be made on either a single component or a complete system, including networking facilities.

The second instrument was developed primarily for making differential gain and differential phase measurements. It produces a staircase type signal to which sine waves of a selected frequency can be added.

The third device is a calibrated phase shifter useful for making accurate phase measurements. The device and a test method are described. This instrument is particularly useful in making precision measurements on system components.

The last instrument described is for frequency measurement. The presence of a color subcarrier makes it important to hold accurately the 4.5 mc sound-to-picture separation. The test instrument reads directly the deviation from the correct spacing with an accuracy of a few cycles.

Introduction

"IT'S BETTER than regular black-and-white." This is a comment frequently given by average TV viewers when asked to rate the quality of the monochrome display of a color television broadcast as seen on their own home receiver. From an engineering point-of-view, a logical explanation for this result is the more careful adjustment and operation of the entire transmitting system. Evidently the more nearly ideal system performance required for color transmission can result in a noticeable improvement in monochrome pictures.

The advent of color television has made routine the measurement and adjustment of equipment characteristics frequently considered of secondary importance or beyond the reach of the average operator. This paper describes test equipment developed to facilitate some of the required measurements.

For a television plant to radiate consistently a color television signal conforming to the signal specifications proposed by the NTSC, the following characteristics will be among those that must be checked:

1. Frequency response
2. Linearity
3. Phase shift at color subcarrier frequency
4. Color subcarrier to aural carrier separation

The instruments to be described will be found useful for checking these factors. They are, in general, self-contained units that do not depend upon external signals.

The Measurement of Frequency Response

Frequency response (that is, the relative output when the input level is held constant in amplitude but varied in frequency) has usually been measured either by the tedious point-by-point method or by sweep-frequency generators. Neither of these is satisfactory for television system checks where black-level clamps are used. To test such circuits, and to check rapidly any television system, a special generator, shown in Fig. 1, was built which

Fig. 1—Exterior view of burst generator.

synthesizes the horizontal sync and blanking signals, and during picture time generates a series of discrete bursts, each of a different frequency. An oscillogram of a typical test signal is shown in Fig. 2. If all bursts are of equal amplitude going into a system, any variation is easily seen in an oscilloscope display at the output or at

Fig. 2—Typical burst generator test signal.

* Decimal classification: R370×R583. Original manuscript received by the Institute, October 15, 1953.
† RCA Laboratories, Princeton, N. J.

any intermediate check point. Since this device has been described elsewhere[1] no details will be given here.

Linearity Measurements

The second instrument to be described is useful for measuring the linearity or differential gain and also the differential phase of a television system. By differential gain is meant the relative output amplitude of a small signal of constant frequency and amplitude as its ac axis is moved throughout the amplitude range of the system. Similarly, the differential phase is the relative phase of the small signal as it is varied throughout the amplitude range. For color television it is most important to have the differential gain be constant at low frequencies, say 100 kc, and at subcarrier frequency. Differential phase must be small at subcarrier frequency.

Fig. 3—Exterior view of linearity test generator.

This instrument, shown in Fig. 3, generates a test signal consisting of simulated horizontal sync and blanking and, during the picture interval, a staircase signal of from 5 to 20 steps. To the steps may be added any one of several frequencies. After passing this test signal through a system, the differential gain is shown by the relative height of the step or the relative amplitude of the sine waves added to the staircase. The differential phase is determined by measuring the phase of the sine waves on each step.

A block diagram of the test generator is given in Fig. 4 and the circuit in Fig. 5 on pages 250 and 251.

The method of obtaining the steps consists of subtracting a high-frequency sawtooth voltage from a low-frequency sawtooth voltage.[2] The low-frequency (15,750 cycle) and the variable-frequency (47 to 315 kc) sawtooth voltages are obtained from multivibrators.[3] The 15,750 cycle multivibrator also generates a square top pulse which is added to the step signal for horizontal blanking. This signal also triggers a multivibrator which generates a narrower pulse to be added to the composite signal for horizontal sync. It also triggers the multivibrator which generates the high-frequency sawtooth wave. A pulse is derived from the variable-frequency multivibrator which is added to the composite signal causing each step to start near black level. A typical test signal, consisting of a five-step staircase, is shown in Fig. 6 on page 252.

The 15,750 cycle multivibrator can be locked to external horizontal sync or to the sine wave signals which are generated internally. It may also be free running, as when an external sine wave is added to the step signal.

The internally generated sine wave signals are obtained from a Hartley oscillator. The five frequencies (0.8, 1.5, 2.5, 3.5, and 4.0 mc) are produced by switching capacitors across the tuned circuit. These may be added to the staircase, one frequency at a time. The signal of Fig. 6, with 1.5 mc sine waves added, is shown in Fig. 7 on page 252.

The output signal of the sine wave oscillator feeds two buffer amplifiers in parallel. The output of one buffer amplifier is added to the step signal. The output of the other amplifier drives a frequency divider.[4] The division factors (10, 9, 6, 4, and 2) vary depending on the frequency of the oscillator, but its output frequency remains constant at 393.75 kc. This signal drives a second divider which divides by five to produce 78.75 kc which locks the 15,750 cycle multivibrator.

The level of the output signal is adjustable from 0 to 2.5 volts peak-to-peak. The amplitude of horizontal sync also is adjustable. As already indicated, different waveforms can be obtained during the horizontal line scanning time. The choice of wave forms depends upon the characteristics one wishes to measure.

The low-frequency differential gain is given by the change in relative height of the steps after passing through the system being tested. Probably the best technique for making differential gain measurements at the sine wave frequencies is to place a high-pass filter between the output of the circuit or system under test and an oscilloscope. The wave form at the output of the high-pass filter is shown in Fig. 8 on page 252. This makes it simpler to detect variations in amplitude.

This device can be employed for a rapid frequency response and linearity check on a system since it requires only the time necessary to turn a switch to five positions (the five different frequencies).

One method of making differential phase measurements is to pass the internally generated sine wave signal (available at a connector on the front panel of the instrument) through a calibrated phase shifter to

[1] H. Borkan, W. C. Morrison, and J. G. Reddeck, "A video test generator," *Electronics*, p. 139; September, 1952.

[2] R. C. Webb, "A Synthetic Pattern Generator for the Solution of Certain Instrumentation Problems in Television," a thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy, Purdue University, June, 1951.

[3] Kurt Schlesinger, U. S. Patent No. 2,383,822.

[4] Peter G. Sulzer, "Modified locked-oscillator frequency dividers," Proc. I.R.E., vol. 39, pp. 1535–1537; December, 1951.

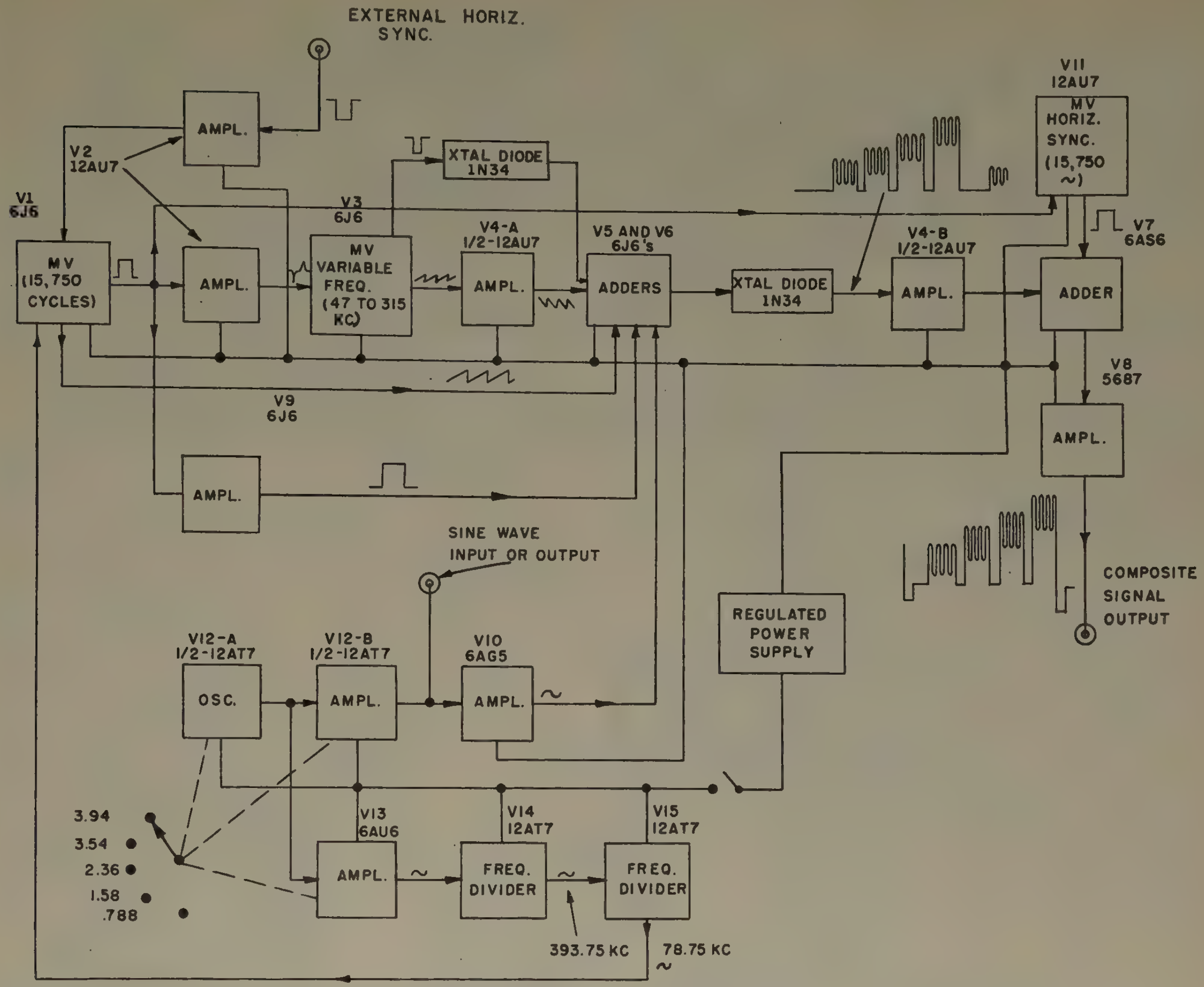


Fig. 4—Block diagram of linearity test generator.

the horizontal plates of an oscilloscope. The composite signal from the output of the device being tested, is placed on the vertical plates of the oscilloscope. The phase shifter is then adjusted to close the Lissajous figure on each step successively. Variations in the phase required to accomplish this is the differential phase. An example of the Lissajous figure display is shown in Fig. 9 on page 252.

To check a circuit or system at frequencies other than the five internally generated sine waves, an external signal may be fed to a connector on the front panel. The 15,750 cycle multivibrator is then free running.

For measurement of the effect of a circuit or system on the color subcarrier, a sine wave at the color subcarrier frequency is added to the steps through the external connection provided. The 15,750 cycle multivibrator, which would then be free-running, may be locked if desired to external horizontal sync through the front panel connector provided. The differential gain and phase of the system can then be measured at the frequency of the color subcarrier as just described.

The differential phase and differential gain characteristics of a system at the color subcarrier frequency can be measured accurately by another method. This requires a test instrument similar to one to be described later which shifts the phase and varies the amplitude of a sine wave at the color subcarrier frequency. The magnitude of the phase shift and the amplitude change are indicated by the test instrument. The sine waves superimposed by the step generator have a variation of about 1 degree from the first to the last step. So, for very accurate measurements, the output signal of the step generator should be measured at input to the system.

Phase Measurements

The third instrument to be described is a subcarrier frequency, precision phase-shifter, with linear phase variation and independent amplitude control.

For color television signals using the NTSC signal specifications, the chromaticity information is transmitted by a subcarrier of 3.58 mc. Amplitude and phase are used to transmit saturation and hue of the colors, respectively. These same NTSC specifications put limits on the unwanted phase shift allowed in the entire trans-

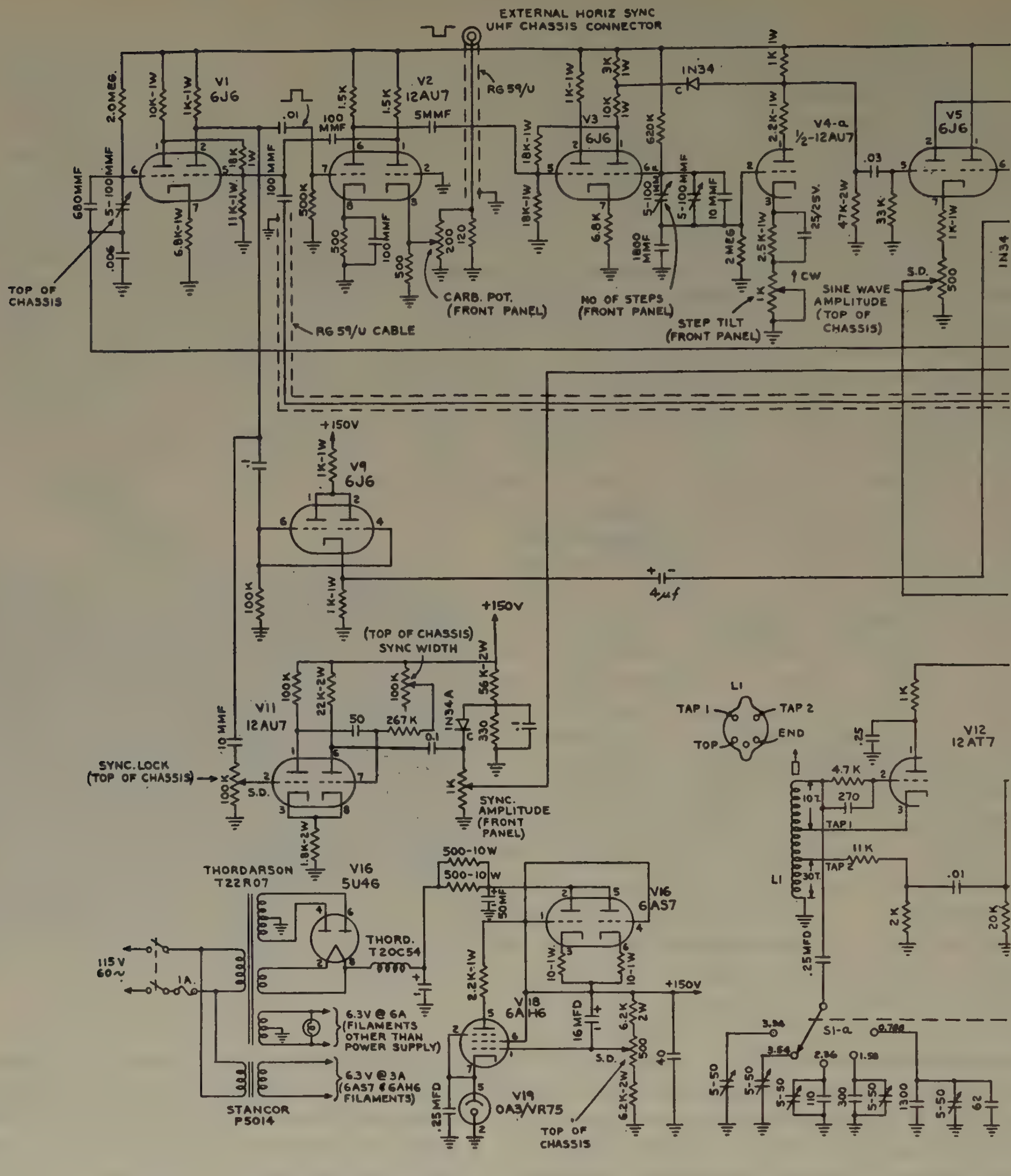


Fig. 5—(left half). Circuit diagram of linearity test generator.

mitting system.[5] To meet these requirements, individual components of the transmitting plant must have very little differential phase error. The phase shifter was developed for measuring the differential phase of individual components of a system, the relative phase of the color subcarrier at various points in a system, and to calibrate other types of phase measuring devices.

Whatever method is used for measuring the phase between two signals, the need for a phase standard to check the accuracy of the measurement is always present. Accordingly, it was decided to assemble phase measuring equipment utilizing as a phase standard a calibrated phase-shifter for indirect measurements. The instrument should be reliable, easy to use, portable, and have high accuracy.

[5] "The angles of the subcarrier measured with respect to the burst phase, when reproducing saturated primaries and their complements at 75 per cent of full amplitude, shall be within ±10 degrees and their amplitudes shall be within ±20 per cent of the values specified above. The ratios of the measured amplitudes of the subcarrier to the luminance signal for the same saturated primaries and their complements shall fall between the limits of .8 and 1.2 of the values specified for their ratios. Closer tolerances may prove to be practicable and desirable with advance in the art." *NTSC Signal Specifications for Color Television,* (pp. 17–19, this issue).

Theory of Operation

Phase measuring, though inherently difficult at all frequencies, is definitely easier to perform at very low frequencies. Good accuracy may be obtained with phase-shifters built on the goniometer principle with crossed magnetic (or electrostatic) fields. Since these devices have a limited frequency range, the thought oc-

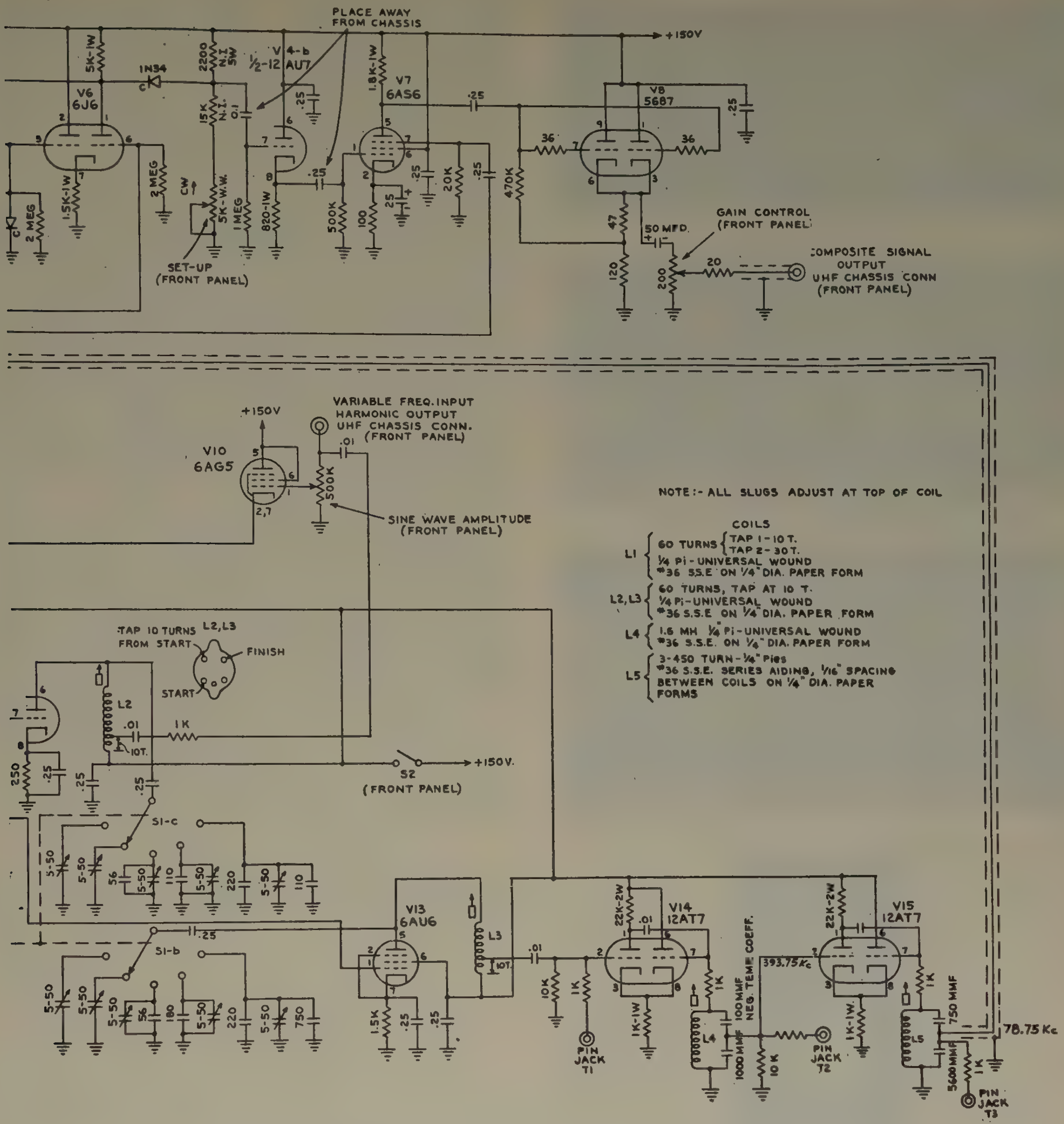


Fig. 5—(right half) Circuit diagram of linearity test generator.

curred to simulate electronically at high frequencies the action of a synchro-resolver.

A sinusoidal function with constant amplitude and linearly varying phase can be synthesized by simple trigonometric manipulation. In one channel, let the sine wave

$$E_s \sin \omega_s t$$

be modulated by $e \sin \phi$ to produce

$$e_1 = E_s \sin \omega_s t \cdot e \sin \phi.$$

In a second channel, each sine wave is shifted 90 degrees prior to modulation to produce

$$e_2 = E_s \cos \omega_s t \cdot e \cos \phi,$$

the sum of these two signals will be

$$e_{\text{out}} = e_1 + e_2 = E_s \cdot e[\sin \omega_s t \sin \phi + \cos \omega_s t \cos \phi]$$
$$= E \cos (\omega_s t - \phi).$$

This function can be obtained electronically as illustrated in Fig. 10. It will be evident that the two 90-degree phase shifters in the one channel could be replaced by a single phase-shifter in the output of that channel if it gave exactly 90 degrees shift of all frequencies produced in the output from the modulator. Furthermore, the quadrature relation between the two signals is the important factor and this may be maintained by dividing the required phase-shift between the two channels as desired.

A block diagram of the method used in this test instrument to produce the adjustable phase sine wave is

Fig. 6—Typical staircase signal.

Fig. 7—Staircase signal with sine waves added.

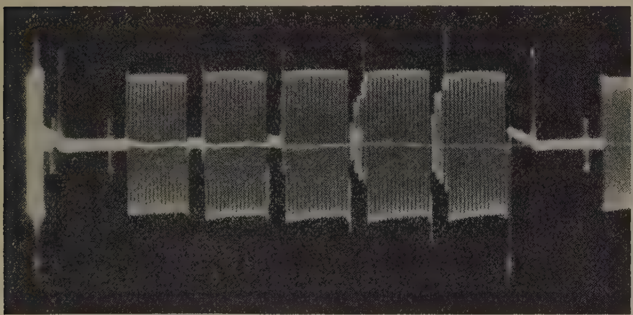


Fig. 8—Test signals after filtering.

Fig. 9—Phase measurement with the test signal.

shown in Fig. 11. Each modulator has two pentodes with their plates in parallel. The grids are driven in push-pull. The bias on the same grids is also varied in a push-pull fashion with an external dc signal. This will unbalance the stage and produce an output sine wave proportional to the amount of unbalance, and with a phase of 0 degrees or 180 degrees according to the polarity of the dc signal. To produce the wanted output signal, the two dc input signals will have to vary as the sine and cosine of an angle, respectively. This can be achieved in practice with a sine-cosine potentiometer. The magnitude of the phase shifted output signal is varied by controlling the dc into the potentiometer. Thus the amplitude and phase controls are completely independent of each other.

Circuit Operations

Balanced Modulator

The incoming signal (3.58 mc) is led through two identical balanced modulator channels. Each modulator stage consists of two 6AK5 tubes with their plates in parallel. The grids are driven push-pull by the carrier, and bias on the same grids is also varied in phase opposition by a second signal. In theory we have a double balanced modulator where only the sidebands appear in the output, and the carrier and modulating signals are suppressed. For the special case used here in which the modulating signal is dc, the sidebands will be at the carrier frequency. This is evident from the following simple analysis.

Assume a sinusoidal modulating voltage causes the effective bias voltage to vary in the same manner. In other words, the transconductance of the tubes oscillates in rhythm with the modulating signal. The resulting transconductance as a time function can be expanded in a Fourier-series. Assuming a linear relationship between grid bias and transconductance, then

$$g_m = g_{m0} + g_1 \cos \omega_m t,$$

where g_{m0} is the transconductance at the quiescent point. When a signal voltage

$$e_{s1} = E_s \cos \omega_s t$$

is applied to the grid of tube 1, the alternating component of plate current will be

$$i_{a1} = g_{m1} \cdot e_{s1} = (g_{m0} + g_1 \cos \omega_m t) E_s \cos \omega_s t$$

$$= g_{m0} E_s \cos \omega_s t + \frac{g_1 E_s}{2} \cos (\omega_s + \omega_m) t$$

$$+ \frac{g_1 E_s}{2} \cos (\omega_s - \omega_m) t.$$

For the plate current in tube 2:

$$i_{a2} = g_{m2} \cdot e_{s2}$$

where

$$g_{m2} = g_{m0} - g_1 \cos \omega_m t,$$

$$e_{s2} = - E_s \cos \omega_s t;$$

then

$$i_{a2} = - g_{m0} E_s \cos \omega_s t + \frac{g_1 E_s}{2} \cos (\omega_s + \omega_m) t$$

$$+ \frac{g_1 E_s}{2} \cos (\omega_s - \omega_m) t.$$

The resulting plate current becomes

$$i_a = i_{a1} + i_{a2} = g_1 E_s [\cos (\omega_s + \omega_m) t + \cos (\omega_s - \omega_m) t].$$

With a dc modulating signal ω_m will be zero, of course.

If the transconductance versus bias is not a linear function over the operating range, a certain amount of harmonic distortion will appear in the output. The plate circuit in the balanced modulator is sharply tuned and discriminates against harmonic components.

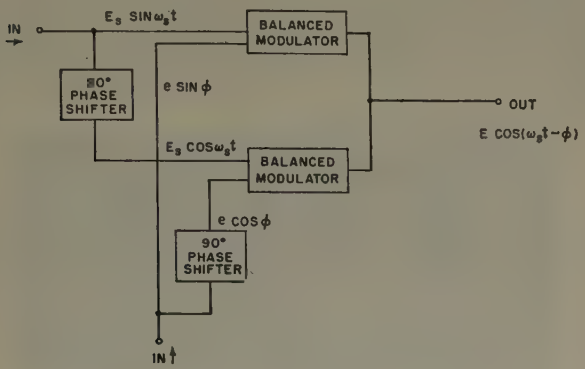


Fig. 10—Method for producing a rotating phasor.

The high frequency push-pull input signal is taken from the plate and cathode of a phase-splitter tube. The plate-resistor and the capacity across the cathode-resistor can be varied to balance the input to the modulator in both phase and amplitude. In order to compensate for the unequal g_m of the 6AK5 tubes, the screen-grid voltage on one tube is variable.

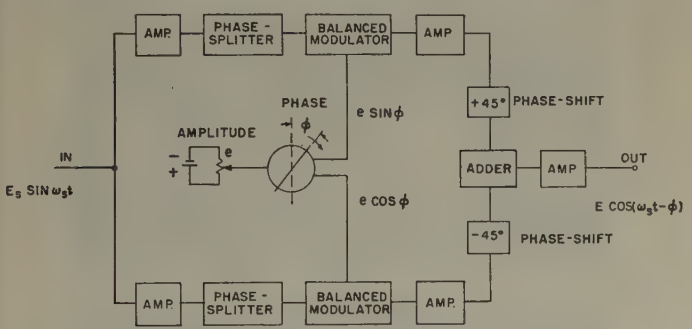


Fig. 11—Block diagram of the phase shifter.

It is vitally important that the modulator stays balanced, and that there is strict linearity between unbalanced output and the dc voltage used to produce the unbalance. A feedback circuit is used to make the modulator self-balancing. It will also linearize the output versus input characteristic of the balanced modulator. A schematic of this circuit is given in Fig. 12. Excessive output from either tube in the modulator will be amplified and reversed in phase, and then fed back to the two cathode circuits in such polarity as to increase the grid-cathode signal on the low gain tube and decrease it on the other. Thus a self-stabilizing action is present tending to reduce the unbalanced output over the whole modulating cycle.

In the input and output of each modulator channel a buffer-amplifier stage is present. These protect the modulators against external changes.

90 Degree-Phase Shifter and Adder

The outputs from the two modulator channels are added in the common plate resistor of two pentodes. In the input circuit of each tube is an RC circuit. The output from one modulator channel is retarded 45 degrees while the output from the other channel is advanced 45 degrees. The net result is to add the output from the two channels in time quadrature.

As previously pointed out, phase-shifters, if located in the output of the modulators, must shift equally all frequencies present. The simple RC circuits used here are adequate only because the modulator output is just the input frequency.

Finally the signal is brought up to sufficient level to give 1 volt rms across 75 ohms.

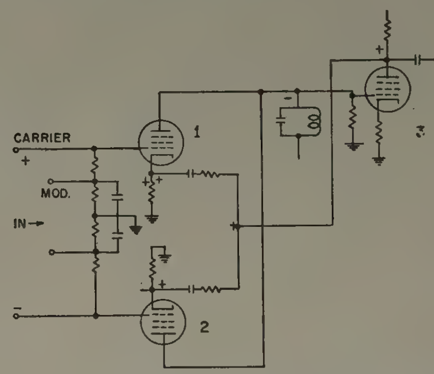


Fig. 12—Application of feedback to balanced modulators.

Sweep Generator

It is desirable to be able to check the performance of the modulator channels quickly and easily. For this purpose a small sweep-generator is built in. It gives a sine wave of approximately 275 cps. The dc signals from the sine-cosine potentiometer, which normally unbalance the modulators, can be replaced by the low frequency sine wave, one channel at a time. The output is taken to the vertical plates of a cro, while the same low-frequency sine wave is taken to the horizontal plates. The display is a bow-tie shaped pattern. The straightness of the two diagonal edges indicates the linearity. The sharpness of the crossing point and its position show how well the modulator is balanced and how symmetrically it is working.

AC Voltmeter

The instrument contains a small ac VTVM which indicates the voltage across the output terminals at all times. It uses a rugged meter (1 ma full scale) and is able to detect 1 mv input. The sensitivity can be decreased with a seven-position switch. The voltmeter is stabilized with negative feedback. It has no zero-point drift or balancing adjustments.

Power Supply

The power supply is of the conventional electronically regulated type. It is capable of delivering 225 ma dc at 225 v. Ripple voltage is below 7 mv at full load.

To Use the Instrument

The complete phase-shifter is shown in Fig. 13. To use the instrument the following is recommended:

1. Set the input signal level. Each modulator channel should have 5 to 6 mv rms on the input. With both modulator and output gain controls at maximum this will be obtained when the built-in voltmeter reads 1.2 volts.

Fig. 13—Exterior view of the calibrated phase shifter.

2. Balance modulator 1. Set the gain control for modulator 1 at maximum, and for modulator 2 at minimum. One complete revolution of the dial should give, with 90 degrees separation, two maxima and two minima readings on the voltmeter. The maxima should be at 0 degrees and 180 degrees, and the minima at 90 degrees and 270 degrees. Starting, for instance, at the 90 degrees mark, the phase is adjusted for minimum reading on the meter. The null is further lowered by the amplitude control. After successive balancing with phase and amplitude controls, even with a maximum reading of 1 volt it should be possible to reach a minimum of the order of 1 mv.

Next, the readings are noted at 0 degrees and 180 degrees. They should be very nearly equal. This condition will be obtained if the balance is sufficiently exact.

3. Balance modulator 2. The same procedure as for modulator 1 is repeated. Of course the two maximum readings will be at 90 degrees and 270 degrees, while the nulls will be at 180 degrees and 0 degrees. After balancing, equalize the output of the two modulator channels. This is done by noting the maxima of the channel with the least gain (with its gain control at maximum), and then adjusting the gain control for the second channel to give the same maxima.

The instrument is, in a way, self-checking. Since ideal conditions give constant amplitude, independent of the dial setting, the amount of amplitude variation is an indication of the final performance. It has been found that it is normally sufficient to use only the two amplitude balancing controls if the instrument has been operating for some time so that temperature equilibrium is reached. For extended periods of operation an occasional check on the balance should be made. With the method outlined this is quickly and easily done. The sweep-generator has not been found necessary for normal use, but, for servicing, it does give a quick and convenient display of each modulator's performance.

This phase-shifter has been checked against an elaborate phase standard with an accuracy of 0.1 degree and was found to be linear within ± 1 degree. The accuracy of measurements made in normal use will depend somewhat upon the signals used. The presence of spurious signals or large amounts of harmonics can make it difficult to obtain an accurate reading.

Analysis of Errors

The output of the phase-shifter should ideally remain constant in amplitude and have a linear phase variation with angular rotation of the potentiometer shaft.

Any error will be due to one or more of the following causes:

1. Error in the sine-cosine potentiometer.
2. Error in the modulator channel.
   a. Amplitude-error.
   b. Phase-error.
3. The two modulator-channels not identical.
4. The signals from the two modulators not added in time quadrature.

Potentiometer error is beyond our control, and determines the ultimate accuracy of the instrument. The unit used is factory guaranteed to have an angular accuracy of ± 0.5 degree and an amplitude accuracy of ± 0.6 per cent.

The output from each modulator-channel must be correct in both amplitude and phase. The first requirement means proportionality between the dc modulating signal and ac output. The second requirement means that for a modulating input signal of varying amplitude, the phase of the output signal is constant with an abrupt change of 180 degrees when the polarity of the modulating signal changes. Measurements show that the output signal varies only a few tenths of a degree over the modulating cycle, except when the modulating signal reverses polarity. Over ± 0.5 degree around this transitory point the output signal may have any relative phase between 0 degrees and 180 degrees. This phase error is unimportant. The null of the modulator is down 60 db from the maximum value, and this residual unbalance is added to the second modulator. At this point the other modulator has maximum output, and the phase and amplitude of the resultant vector is negligibly different from the theoretical value.

Some Applications

One of the primary applications for this instrument was to measure phase and amplitude of the color subcarrier corresponding to known colors.

In Fig. 14(a), is shown one line of a composite color video signal, which is a color-bar test pattern. The burst can be seen on the back porch of horizontal blanking and the bars represent from left to right:

green, yellow, red, magenta, blue, cyan, and green. Each bar of the subcarrier frequency shall have, according to NTSC signal specifications, a definite value of relative amplitude and phase referred to the burst.

The measuring technique is as follows: The phase-shifter is fed by a cw reference signal of color subcarrier frequency. The output of the phase-shifter is added to the composite video and taken to the vertical plates of a cro. The scope, together with the eyes, acts as a very sensitive null detector.

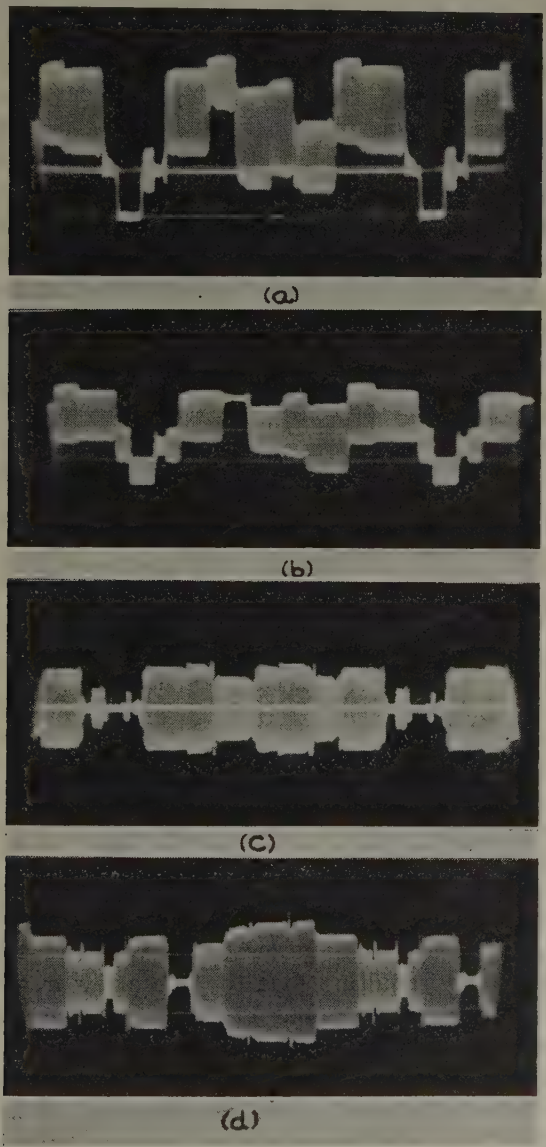


Fig. 14—Color-bar test pattern.

By adjusting the phase and amplitude controls, a certain color bar in the test pattern can be cancelled out completely, as shown in Fig. 14(b).

A high-pass filter is recommended which can be switched in or out of the input to the scope. The original signal is then as in Fig. 14(c), and with one bar cancelled out as in Fig. 14(d). An amplified and expanded part of the yellow bar when cancelled out is shown in Figs. 15(a) and (b). Apparently there is some variation of phase over the bar and the two cases shown represent a phase-shift of 4 degrees and a negligible change in amplitude. In Fig. 15(c), the green bar is measured. The variations across this bar are much less.

The phase dial can be unlocked from its axis and rotated to any selected position. In practice the burst is cancelled out first and the phase scale is set to read 180 degrees (or 0 degrees). The color-bars in the test pattern are then cancelled one after the other, and corresponding phase angles and amplitudes read off directly.

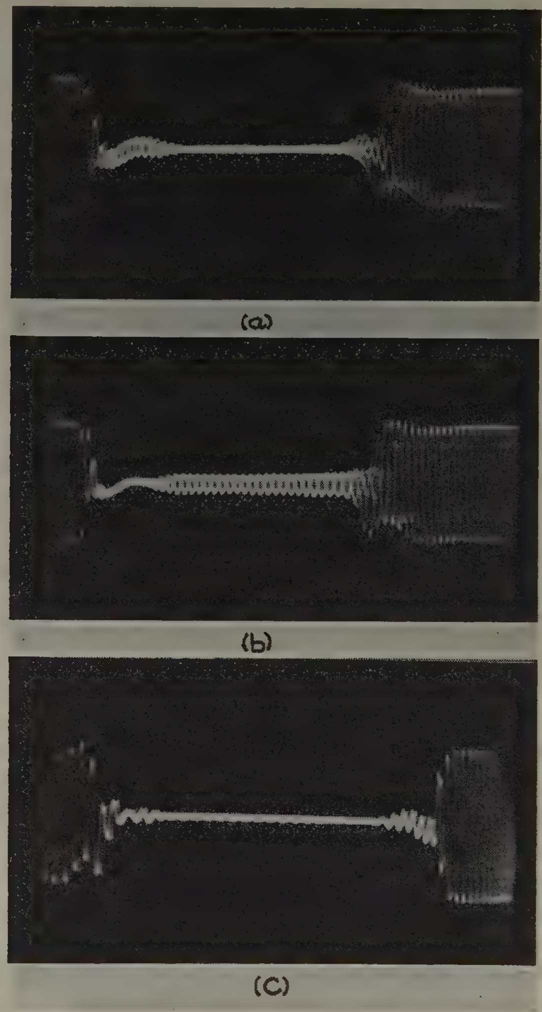


Fig. 15—One bar expanded.

In receivers, the color subcarrier is regenerated by converting the burst into a cw signal. Various schemes are used for this, such as crystal ringing circuits and reactance controlled oscillators. It is desirable to be able to study the phase variations over a line or a field. This is a simple operation with the method outlined.

The differential phase and differential gain characteristics of a system can be measured accurately with this phase-shifter in combination with the step-generator described earlier.

The test procedure is to pass the step signal with the added color subcarrier frequency through the system under test. At the output of the system the signal is combined with the color subcarrier frequency which has passed through the calibrated phase-shifter. The

amplitude and phase of the sine wave can be changed then until the signal which has passed through the system is cancelled to zero for each step.

This method of phase measuring gives an excellent way of studying at leisure phase variation as a function of time.

Simplified Phase Measuring Equipment

Once a precision phase-standard is available for calibration purposes, much simpler phase measuring devices can be devised. One approach that has been tested to some extent is shown in Fig. 16.

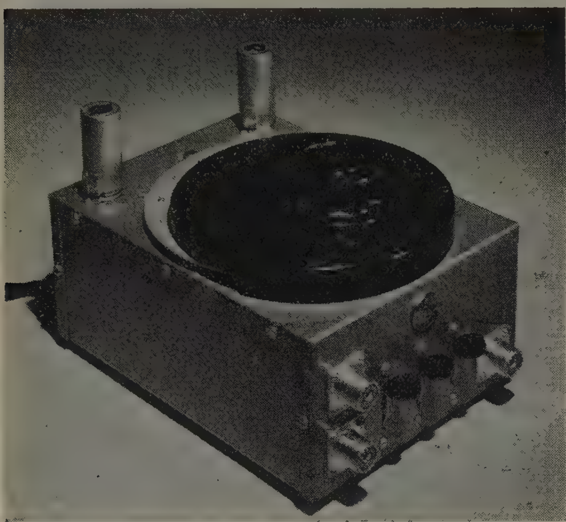


Fig. 16—A delay line phase shifter.

This device makes use of a commercially available variable delay line to obtain the adjustable phase sine wave. The delay line is isolated from external changes by cathode followers at both the input and output.

Although it lacks some of the refinements of the phase-standard, this phase-shifter is a very useful device. No attempt was made to include an output voltmeter and some fixed delay must be added to cover a full 360 degrees at color subcarrier frequency. On the other hand, no tuned circuits are used which would limit the bandwidth of the device and it is certainly portable and rugged.

A 4.5-MC Beat Meter

Even casual observers have probably noted that mild interference patterns in television pictures tend to vary in intensity. For certain types of interference this can be explained by interlacing. For example, any sinusoidal variation that occurs at a multiple of line frequency will modulate the picture brightness in the same manner for each line scanned. The result is a distinct and easily observed pattern. If the interfering frequency changes so that it is an odd multiple of one-half line frequency, the pattern is broken up and interlaces in such a way that visibility is materially reduced.

The color signal is susceptible to additional interferences beyond those normally encountered with monochrome because of the subcarrier used for the color information. In addition to the usual low-frequency beats visible in a monochrome picture, it is also possible for higher frequencies to beat with the subcarrier and produce a low-frequency high-visibility pattern. In some receivers, the normal sound carrier may mix with the color subcarrier to produce a beat frequency of about 900 kilocycles. The resulting pattern is coarse enough to be very objectionable if seen. Fortunately, normal receiver design has, in most cases, reduced the mixing of these signals so that the beat is hardly visible. Additional improvement can be obtained by causing the beat to interlace, as previously described. Tests have been made which show how the visibility of the beat pattern changes as the interfering frequency is varied from maximum to minimum visibility. This curve is shown in Fig. 17. It is evident, of course, that the fre-

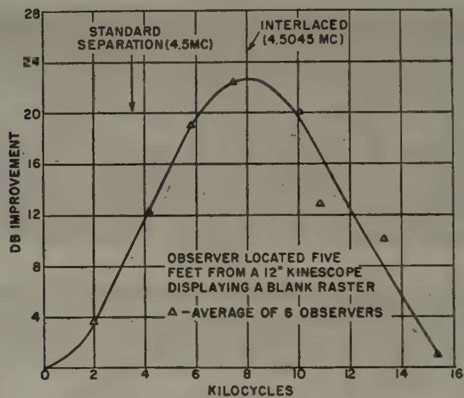


Fig. 17—Sound-subcarrier beat interference.

quency modulation of the sound carrier upsets the interlacing but observation has shown that interlace during quiet periods is still to be perferred. Since it is impossible to hold any frequency exactly, the NTSC signal specifications indirectly provide for this beat frequency to be maintained within about 1000 cycles. This is accomplished by requiring that the subcarrier frequency be maintained within about 11 cycles and the spacing between sound and picture carriers be maintained within 1,000 cycles of the 4.5 megacycle separation. To assure interlace of both the subcarrier and the sound-subcarrier beat, the line frequency has been adjusted so that 4.5 megacycles (the sound-to-picture spacing) is an even multiple of line frequency, then the subcarrier is made an odd multiple of half line frequency. This, of course, leaves another odd multiple of half line frequency between subcarrier and sound carrier (Fig. 18).

With present transmitters, the maintenance of the intercarrier spacing within 1,000 cycles is somewhat of a problem. First, the frequency measuring devices normally available at the transmitter have not been designed to maintain the required accuracy, and second, the crystals used to control the transmitters are even less stable. From this it is evident that a more reliable de-

vice that would quickly and accurately measure the picture-to-sound carrier spacing would be a useful piece of equipment.

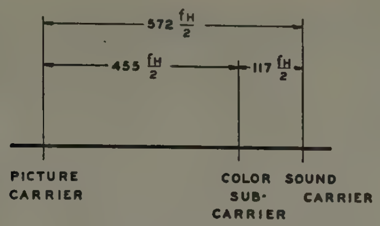


Fig. 18—Spacing within a channel.

Two approaches are available. Either a relatively accurate device with great reliability and stability or else a device with adequate accuracy, short term stability, and built-in self-checking means will serve.

The system to be described uses the latter method. It will measure accurately the frequency difference between the sound carrier and the picture carrier of stations operating on any channel from 2 through 13. By using a converter, the range can be extended to cover the uhf assignments.

It is intended to have sufficient stability to operate for weeks without recalibration, however, self-calibration of the frequency standard is included as a precaution and for set-up after the unit has been moved or has been inoperative for a period. A block diagram of the system is shown in Fig. 19.

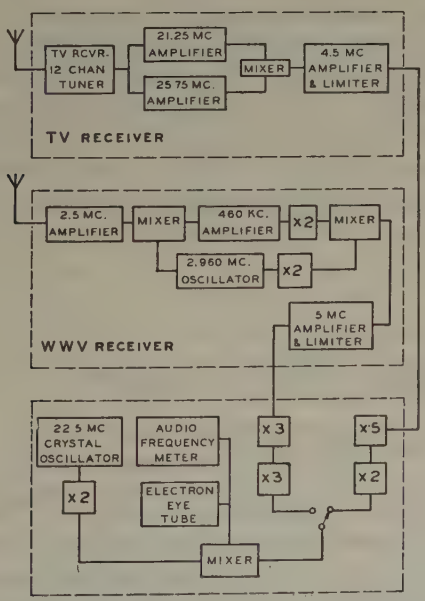


Fig. 19—Block diagram of the beat frequency meter.

Circuitry

The beat meter consists of several components. First, there is a television channel receiver designed simply for high gain, mixing of the sound and picture carriers, and amplification of the 4.5 mc sound-to-picture beat. Second, a high stability crystal-controlled frequency against which to compare the beat frequency. Third, a means for obtaining an independent high stability signal for checking the crystal. And fourth, means for combining the crystal controlled signal with either the reference signal or the unknown signal and measuring the difference in each case.

The television station receiver consists of a standard 12 channel detent type television tuner followed by two parallel narrow-band IF channels. One is tuned to 21.25 mc to amplify the sound carrier, the other is tuned to 25.75 mc to amplify the picture carrier. The two IF channels feed a mixer tube to produce the 4.5 mc difference frequency. The mixer is followed by a 4.5 mc amplifier and limiter system to minimize amplitude variations. A sound take-off is provided to aid tuning and to identify the received station.

This receiver has rather high sensitivity so that it can be used to check a television transmitter at a remote point. In order to make the device useful in close proximity to a transmitter, rather elaborate shielding has been employed. The entire receiver is enclosed in a aluminum box, the incoming power leads are filtered, the coaxial antenna lead interposes a high-pass filter between the tuner and the antenna connector and, finally, the incoming signal can be attenuated by external coaxial pads.

The frequency standard employs an RCA Type TMV-129P crystal operating at 22.5 mc in the circuit recommended for such service. As used in transmitting stations, these units can be expected to deviate less than 0.00005 per cent in a 30-day period. This is less than 3 cycles at 4.5 mc which is more than adequate for checking a 1,000-cycle tolerance.

In order to set or check the crystal frequency, a second receiver is provided. This is a fixed frequency receiver tuned to 2.5 mc to receive the standard-frequency transmission from WWV. The 2.5 mc signal is amplified and then heterodyned with a 2.960 mc signal to 460 kc. Selectivity and sensitivity are obtained with an amplifier at this frequency. The signal drives a class C doubler to produce 920 kc which is then mixed with twice the local oscillator frequency ($2 \times 2.960 = 5.920$ mc) to produce a 5 mc signal having very nearly the same accuracy as the incoming 2.5 mc signal. With this system the output frequency is independent of any reasonable variation of the local oscillator.

To review, we have a 4.5 mc signal to be checked, a 22.5 mc frequency standard, and a 5 mc standard-frequency derived from WWV. These can all be brought to a common frequency of 45 mc by multiplication. The crystal frequency is doubled. The 4.5 mc beat is multiplied by 5 and then by 2 in two class C stages. The 5 mc signal is multiplied by 9 in two states, each operating as a class C tripler.

By appropriate switching, the 45 mc from the crystal can be mixed with either the reference frequency derived from WWV or with the 45 mc from the sound-to-picture carrier beat. In each case the resulting difference frequency, if less than a few cycles per second, can be observed on an electron eye tube. If the differ-

ence is more than about 20 cycles the beat can be measured on an audio frequency meter. This last device does not need to be a precision instrument since frequency multiplication has been employed. For example, an error of only 10 cycles in the 4.5 mc beat would appear as 100 cycles on the audio frequency meter.

Operation

The method of operation of this frequency meter is apparent from the preceding description of the components. The crystal is set on frequency by comparing it with the WWV signal. (This is no problem for the accuracy required in this application, however, vagaries of propagation may cause the WWV signal to vary and thus make it appear that the crystal is not stable.) Next the television receiver is tuned to the station that is to be checked and the crystal switched to mix with the TV receiver output. The beat can then be counted on the electron eye tube or read on the audio frequency meter. Obviously, readings cannot be taken with sound modulation on since it is frequency modulation of the sound carrier. The results are also influenced to some extent by picture modulation so it is necessary to remove all modulation before accurate results can be obtained.

The instrument, as shown in Fig. 20, has been used to check a transmitter at a time when simultaneous checks could be made by a commercial frequency measuring service. The readings taken with the new instrument were all within ±10 cycles of the readings made by the measuring service. At least part of this error could be attributed to the audio frequency meter.

One shortcoming in the system is that no indication is given as to whether the unknown frequency is higher or lower than the reference. For the use intended this is not important; however, it is a limitation on the general application of the method.

Fig. 20—Exterior view of the beat frequency meter.

Conclusion

The development of color television has shown the need for unfamiliar system tests and maintenance. As these requirements have developed, new pieces of test equipment have been made which simplify the necessary measurements so that they become routine.

Some of these instruments have been described in this paper. As might be expected, there is some overlap in the measurements that can be made with each device. This is a natural result of a rapidly developing field. Future builders may well produce other combinations that appear to them to be better adapted to their work. The fortunate outcome will be better television pictures, in monochrome as well as in full color.

Delay Equalization in Color Television*

G. L. FREDENDALL†, senior member, ire

Summary—**The signal-delay characteristics proposed by the NTSC for a television transmitter for color provides for the equalization of the delay distortion associated with the high-frequency cutoff of the average receiver.**

A design for an equalizer is developed with the aid of the potential analogy for all-pass filters.

Introduction

THE FULL CAPABILITIES of a color or monochrome television system for the faithful production of an image pass unrealized unless sources of video waveform distortion not inherent in the over-all system are substantially either removed or equalized. All video frequency and carrier frequency circuits from the camera to the receiver are included in the system.

The over-all envelope delay in the unequalized state is definitely frequency dependent and therefore detracts from the fidelity of the system whether monochrome or color. Delay distortion is largely concentrated in the intermediate frequency and video frequency divisions of the receiver near both ends of the channel where the amplitude response changes most rapidly. The color subcarrier and sidebands and the high video frequencies of the luminance signal suffer delay distortion rela-

* Decimal classification: R583. Original manuscript received by the Institute, October 15, 1953.
† RCA Laboratories, Princeton, N. J.

tive to midband frequencies on account of trap circuits for the attenuation of the associated sound signal.

Among the pictorial defects attributable to delay distortion are excessive ringing in the luminance information and smeared and spurious color edges at transitions in the color information.

Past experience indicates that the envelope delays of color receivers will be sufficiently similar for the concept of the delay of the "average receiver" to be useful. The NTSC has specified in effect that a delay equalizer should be inserted in the video input of the transmitter for equalization of cutoff delay of average receiver.[1]

Section III, paragraph B of the petition to the FCC:

> "A sine wave, introduced at those terminals of the transmitter which are normally fed the color picture signal, shall produce a radiated signal having an envelope delay, relative to the average envelope delay between 0.05 and 0.20 mc, of zero microseconds up to a frequency of 3.0 mc; and then linearly decreasing to 4.18 mc so as to be equal to -0.17 μsec at 3.58 mc. The tolerance on the envelope delay shall be ± 0.05 μsec at 3.58 mc. The tolerance shall increase linearly to ± 0.1 μsec, down to 2.1 mc, and remain at ± 0.1 μsec down to 0.2 mc. The tolerance shall also increase linearly to ± 0.1 μsec at 4.18 mc."

The delay specified in the proposed standard becomes the equivalent video delay of the transmitter and all associated transmitter terminal equipment including the receiver cutoff delay equalizer.[2] If it is assumed that the delay of the transmitter equipment is flat, the specification applies only to the cutoff delay equalizer.

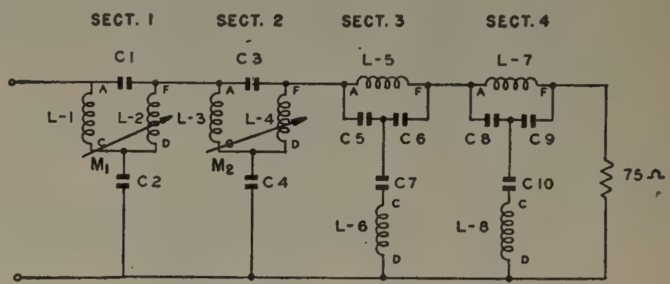
This paper describes a particular equalizer that satisfies the NTSC specification and then briefly traces the steps taken in reaching the design.

Design for an NTSC Delay Equalizer

Several design procedures are available for delay equalizers including 1: trial and error,[3–5] 2: potential analogue,[6] 3: approximation methods using Taylor's Series or Tschebycheff Polynomials,[7] and 4: combinations of 1, 2, and 3. A combination of 1 and 2 was employed in the design of the cutoff delay equalizer shown in Fig. 1.[8] The delay of the equalizer and the NTSC specified delay with tolerances are shown in Fig. 2.

Structurally, the equalizer consists of four conventional, all-pass sections. Sections of this type have a flat amplitude-frequency response except for the attenuation caused by incidental dissipation in the inductors and capacitors. The constant resistance feature of the all-pass section permits direct termination of coaxial cables and other apparatus requiring constant resistive termination. It is frequently convenient to insert an equalizer in a 75 ohm circuit. Hence the present design was based on a 75 ohm characteristic impedance.

Section delay characteristics 1 and 2 in Fig. 2 require negative mutual inductive coupling in the bridged-T network. Characteristics 3 and 4 may be realized in the bridged-T network without mutual coupling—a desirable possibility.



Element	microhenries	Element	micromicro-farads
L_1	11.0	C_1	468
L_2	11.0	C_2	5980
M_1	-5.78		
L_3	5.87	C_3	468
L_4	5.87	C_4	2300
M_2	-0.61		
L_5	5.82	C_5	935
L_6	2.63	C_6	935
		C_7	2300
L_7	4.68	C_8	831
L_8	2.29	C_9	831
		C_{10}	1709

Fig. 1—Cutoff delay equalizer.

The pole and zero pattern of the filter shown in Fig. 3 is an application of the "condenser plate" analogy in the potential analogue method of equalizer design.[8] Poles and zeros are identified with the sections to which they belong. The remote pairs of poles and zeros depart somewhat from the regular spacing so that a better approximation to the desired delay characteristic is obtained.

The delay specified by the NTSC is approximated to within ± 0.01 μsec at all points except those lying near the point of discontinuity at 3 mc where the approximation is within ± 0.02 μsec. Since delays contributed by the individual sections have a "staggered tuned" aspect, submultiples of the over-all delay cannot be tapped off at interstage points within the equalizer.

Construction and Alignment of the Delay Equalizer

If the values of all elements in the equalizer lie within ± 1 per cent of the theoretical values, a satisfactory delay characteristic and input impedance results. Accuracy of this order is not difficult to achieve if ordinary laboratory standards are available.

[1] Petition of NTSC for Adoption of Transmission Standards for Color Television; July 21, 1953.

[2] In specifying the phase characteristic in terms of envelope delay, the assumption is tacitly made that phase intercept distortion for the range of significant frequencies is either zero or negligible.

[3] A. R. A. Rendall, "Design of phase compensation networks," *Elec. Commun.*, vol. 7, pp. 316–327; April, 1929.

[4] W. Sarga, "Attenuation and phase shift equalizers," *Wireless Eng.*, vol. 20, pp. 163–181; April, 1943.

[5] J. W. Allnatt, "The delay equalization of the London-Birmingham television cable system," *Proc. IEE*, vol. 99, part 111a, pp. 338–347; April/May, 1952.

[6] S. Darlington, "The potential analogue method of network synthesis," *Bell Sys. Tech. Jour.*, vol. 30, pp. 315–363; April, 1951.

[7] V. H. Grinich, "On the Approximation of Arbitrary Phase-Frequency Characteristics," Tech. Report No. 6 , Electronics Research Lab., Stanford University, Stanford, Calif.

[8] See Appendix.

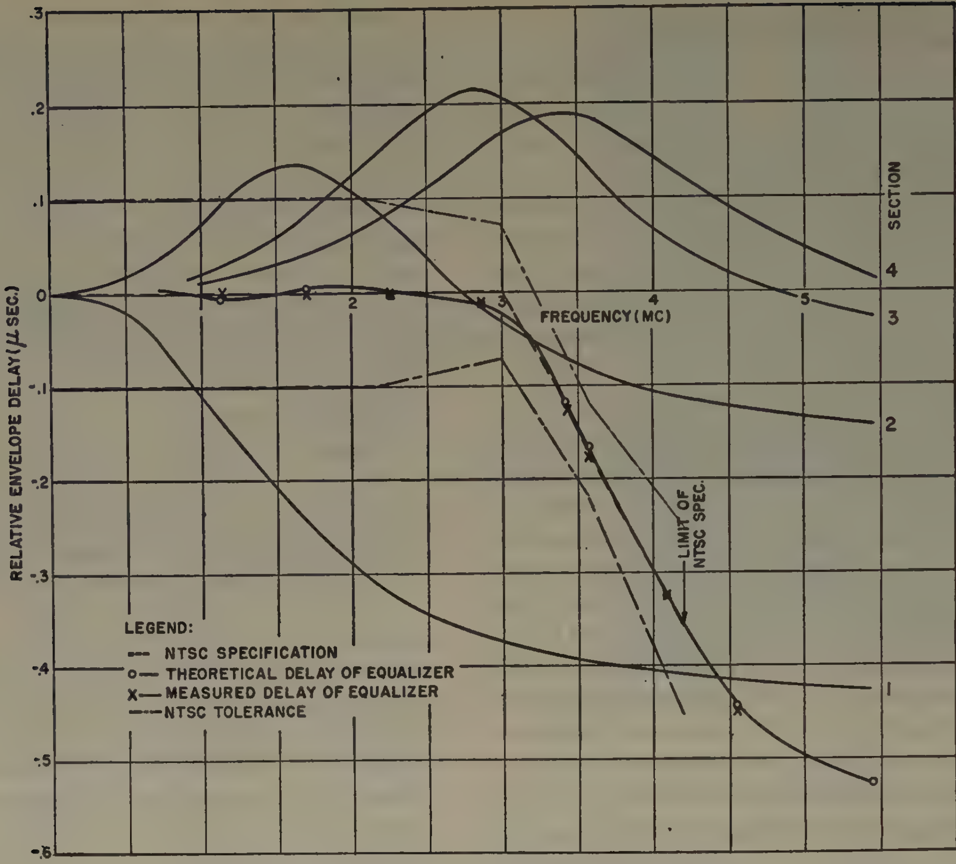


Fig. 2—Envelope delay characteristic of equalizer.

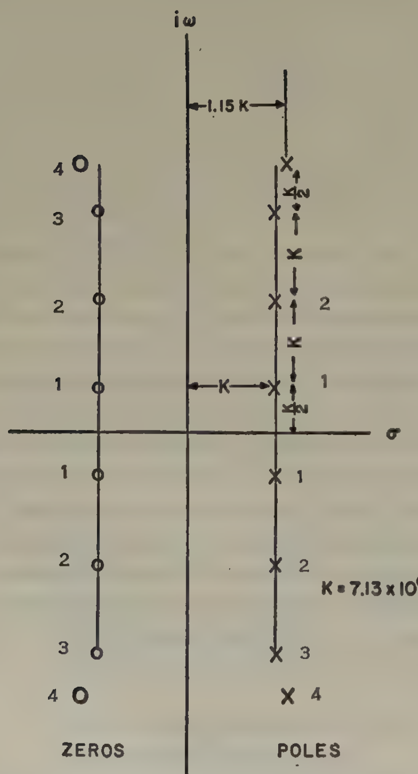


Fig. 3—Pole and zero pattern of delay equalizer.

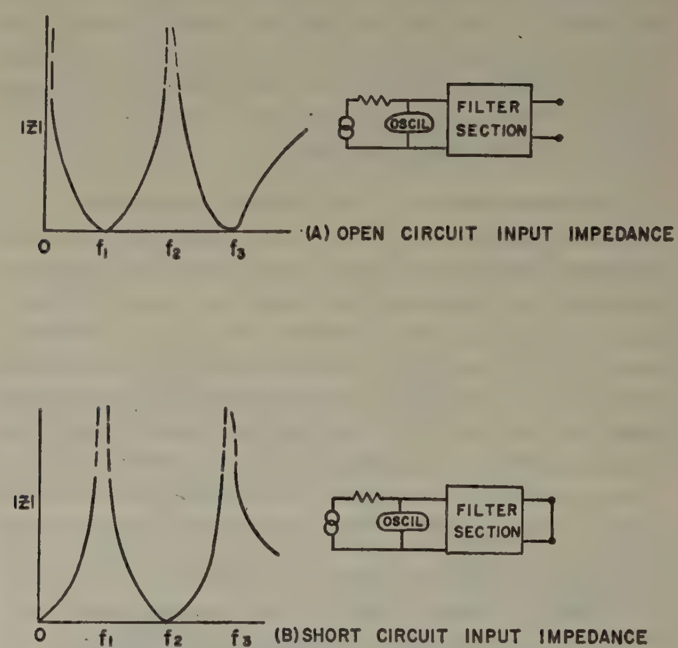


Fig. 4—Open and short circuit input impedances of delay equalizer.

Short circuit and open circuit tests may be made on each isolated section of the equalizer as a check on element values. An oscilloscope or any measuring device capable of indicating maxima and minima of input impedance is connected as illustrated in Fig. 4. The variation of input impedance should follow the trend shown in Fig. 4 and frequencies corresponding to 0 and infinite input impedances should agree within approximately ±1 per cent of the theoretical values entered in Table 1.

TABLE I
Open and Short Circuit Test Frequencies

Section	f_1 mc	f_2 mc	f_3 mc
1	0.563	1.27	2.84
2	1.21	2.05	3.48
3	2.13	3.06	4.41
4	2.57	3.65	5.20

Another check on the accuracy of construction of the equalizer is the observation of reflections by means of a frequency sweep and an oscilloscope connected across the input end. The input envelope should be flat theoretically. In an actual filter, ripples of ±5 per cent are probably tolerable. There is a temptation to flatten the input envelope by touching up the element values in the completed filter. This may sometimes be accomplished with success, especially if the individual sections are disconnected and observed separately for reflections.

Appendix

The electrostatic analogy of all-pass sections is helpful in making available to the designer the knowledge he may have of simple electrostatic configurations for visualization of the more abstract delay characteristics of such networks. The analogy is developed as follows:

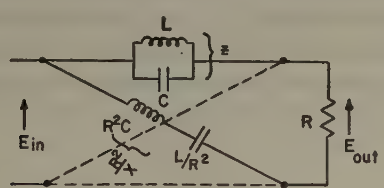


Fig. 5—All-pass lattice section.

Kirchoff's Laws when applied to the all-pass lattice section shown in Fig. 5 lead to,

$$\frac{E_{\text{in}}}{E_{\text{out}}} = \frac{R+Z}{R-Z} = \frac{p^2 + \dfrac{L\omega_0^2}{R}p + \omega_0^2}{p^2 - \dfrac{L\omega_0^2}{R}p + \omega_0^2} \tag{1}$$

where

$$\omega_0 = 1/\sqrt{LC}$$
$$p = j\omega.$$

The phase shift β and the attenuation α are defined in terms of the voltage ratio (1) as

$$\epsilon^{\alpha}\angle\beta = \frac{E_{\text{in}}}{E_{\text{out}}}\cdot$$

Since α is zero for all frequencies in the all-pass lattice, (1) becomes

$$\epsilon^{j\beta} = \frac{p^2 + \dfrac{L\omega_0^2}{R}p + \omega_0^2}{p^2 - \dfrac{L\omega_0^2}{R}p + \omega_0^2}$$

$$= \frac{(p+K_1+j\omega_1)(p+K_1-j\omega_1)}{(p-K_1+j\omega_1)(p-K_1-j\omega_1)} \tag{2}$$

where

$$K_1 = \frac{L\omega_0^2}{2R}$$
$$\omega_1^2 = \omega_0^2 - K_1^2.$$

The phase shift β is solved from (2)

$$j\beta = \log(p+K_1+j\omega_1) + \log(p+K_1-j\omega_1) - \log(p-K_1+j\omega_1) - \log(p-K_1-j\omega_1)$$
$$= \log\sqrt{K_1^2+(\omega\times\omega_1)^2} + j\tan^{-1}\frac{\omega+\omega_1}{K_1} + \log\sqrt{K_1^2+(\omega-\omega_1)^2} + j\tan^{-1}\frac{\omega-\omega_1}{K_1}$$
$$- \log\sqrt{K_1^2+(\omega+\omega_1)^2} - j\tan^{-1}\frac{\omega+\omega_1}{-K_1} - \log\sqrt{K_1^2+(\omega-\omega_1)^2} - j\tan^{-1}\frac{\omega-\omega_1}{-K_1}\cdot$$

Therefore

$$\beta = \tan^{-1}\frac{\omega+\omega_1}{K_1} + \tan^{-1}\frac{\omega-\omega_1}{K_1} + \tan^{-1}\frac{\omega+\omega_1}{K_1} + \tan^{-1}\frac{\omega-\omega_1}{K_1}\cdot$$

The envelope delay $d\beta/d\omega$ is

$$\frac{d\beta}{d\omega} = \frac{K_1}{K_1^2+(\omega+\omega_1)^2} + \frac{K_1}{K_1^2+(\omega-\omega_1)^2} + \frac{K_1}{K_1^2+(\omega+\omega_1)^2} + \frac{K_1}{K_1^2+(\omega-\omega_1)^2}\cdot \tag{3}$$

If the variable, p is now regarded as a complex variable representing any point in the complex p plane, the transfer function given by (2) acquires zeros at p_1 and p_2 and poles at p_3 and p_4 at which the function is zero and infinite. The quadrantal symmetry of poles and zeros is illustrated in Fig. 6(a). Of course (2) has physical significance only when p is restricted to the imaginary axis in Fig. 6(a).

The electrostatic analogy is introduced at this point. Uniform positively charge filaments infinite in extent are placed perpendicular to the p plane at the two zeros of the transfer function and negatively charged filaments are placed at the poles. Application of potential theory shows that the component of electric intensity on the jw axis and normal to that axis due to the filament at the zero, p_1 is proportional to[9]

$$\frac{K_1}{K_1^2+(\omega-\omega_1)^2}\cdot \tag{4}$$

[9] S. S. Attwood, "Electric and Magnetic Fields," John Wiley and Sons, New York, N. Y., 3rd ed.; 1949.

Equation (4) has the same form as the delay due to the same zero in (3). In a similar manner, the contributions to the electric intensity from the other zero and poles may be matched with corresponding terms in (3). It is concluded that the envelope delay of the all-pass lattice section of Fig. 5 is proportional to the intensity normal to the *jw* axis due to the four line charges. This analogy means that the designer may locate line charges in quadrantal symmetry to produce an intensity normal to the *jw* axis similar to the delay characteristic. The locations of the line charges become the zeros and poles of the all-pass section. A multisection network may be treated in the same manner since the linear superposition of delay due to poles and zeros is valid.

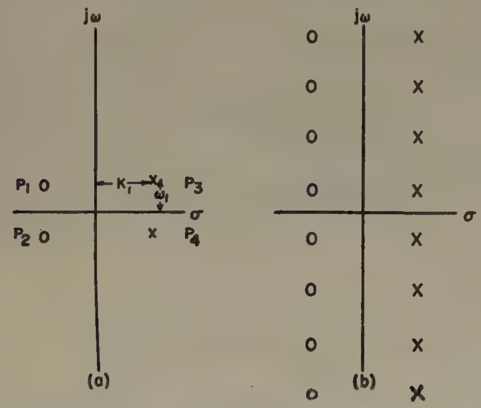


Fig. 6—(a) Pole and zero pattern of lattice. (b) Pole and zero pattern of 4-section lattice according to the condenser plate potential analogy.

The application of the potential analogue in the design of the cutoff delay equalizer may be given now. The proposed delay specification includes an interval of constant delay from 0.2–3 mc and a linear roll off thereafter. As a first approximation, the zeros and poles may be equally spaced as indicated in Fig. 6(b) since such an array of line charges at the critical points yield a more or less uniform electric intensity normal to the *jw* axis in the region of the wires and a decreasing intensity on the axis beyond the last pole and zero. The regular array of poles and zeros would be expected to extend over the entire frequency interval of uniform delay, i.e., 3 mc. Actually, the variation of the electric intensity may be expected to contain a ripple component as a consequence of the concentrated nature of the charges in the field. The amplitude of the ripple will obviously increase as the zeros and poles approach each other and the interpole distance remains fixed. In general, the pole to zero spacing that yields the largest permissible ripple in the envelope delay results in the most economical equalizer.

The number of poles and zeros and the pole to zero spacing may be determined by trial and error. In the present design, four sections or 8 poles and 8 zeros and a pole to zero spacing equal to two times the interpole spacing were found to be satisfactory. After a preliminary calculation indicated that the roll off of the specified delay could not be approximated with sufficient accuracy by a regularly spaced array, the positions of the outer pairs of zeros and poles were adjusted until the approximation shown in Fig. 3 resulted.

Modification of Cutoff Delay Equalizer for Vestigial Sideband Equalization

The delay of the average vestigial sideband filter requires equalization over a frequency interval approximately 2 mc in width centered about the picture carrier. In terms of the equivalent video frequency delay for sufficiently low depths of modulation, there is excessive delay at low frequencies. Fig. 7 illustrates the delay characteristic.

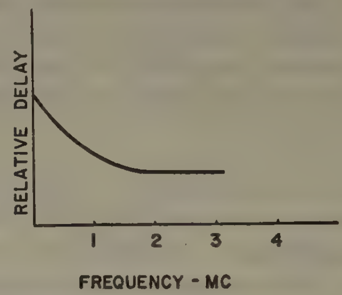


Fig. 7—Equivalent video delay characteristic of vestigial sideband filter.

The potential analogy of all-pass sections is again helpful in indicating how the delay cutoff equalizer may be modified—or a new one designed—for equalization of low-frequency delay distortion.

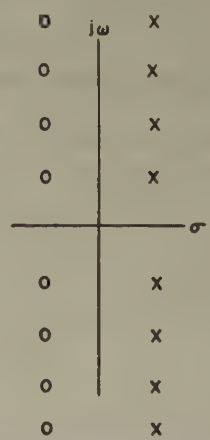


Fig. 8—Illustrative pole and zero pattern of an equalizer for vestigial sideband filter delay distortion.

Since the delay of the equalizer must be complementary to that shown in Fig. 7 the delay at low frequencies must be relatively lower. It is not difficult to visualize how the pole and zero configuration in Fig. 6(b) may be modified to yield an electric intensity in the potential analogue which diminishes in the vicinity of the origin. The required change is accomplished by a movement away from the origin in the direction of the *jw* axis of poles and zeros without disturbing their relative spacing (Fig. 8). A redetermination of the value of "*k*" shown in Fig. 3 could proceed by trial and error.

Alignment of a Monochrome TV Transmitter for Broadcasting NTSC Color Signals*

JOSEPH F. FISHER†, SENIOR MEMBER, IRE

Summary—**This paper describes the measurements and alignment techniques that were used at Television Station WPTZ (Philadelpha) to successfully broadcast a certified NTSC color signal.**

Certification data were taken using a standard color-bar chart, the phase and amplitude of the color subcarrier being measured with a vectorimeter having a polar display. Additional equipment employed consisted of a wide-band oscilloscope, ten-step staircase generator, frequency burst generator, transmission-line monitor, and a special stabilizing amplifier modified for color operation.

Introduction

THE NTSC SYSTEM of color television transmits information about the coloring in a scene by means of phase and amplitude modulation of a subcarrier, having an equivalent video frequency of 3.58 mc.

To reproduce a color sample or patch placed in front of a color camera, or a color generated synthetically from a color-bar generator, requires the transmission of three pieces of information to completely define the color. The three pieces of information required are first, a signal related to the hue of the color (whether it is red, yellow, green, blue, etc.), second, a signal related to the saturation, which is a measure of the dilution of a saturated color by white light, and third, a signal related to the luminance.

In addition, a reference color sync signal is transmitted on the back porch of all the horizontal blanking pulses. This signal consists of 8 cycles of a 3.58-mc sine wave having a constant phase. Hue is transmitted by phase modulation of the subcarrier, and as a result each of the saturated spectral colors has a definite phase angle associated with it. Saturation affects the amplitude of the subcarrier, and if a transmitted primary color sample is desaturated and held at constant luminance, the phase of the subcarrier remains constant while the amplitude decreases.

The information about the luminance of the color picture elements in a scene is transmitted primarily by amplitude modulation of the picture carrier. In addition, the signal is so packaged that when picture elements containing no color, such as shades between black and white, are transmitted, the color subcarrier reduces to zero and the monochrome luminance variations are also transmitted by amplitude modulation of the picture carrier.

Since additional information is being transmitted in the 6-mc television channel, there are certain precautions that must be taken to insure that the coloring and luminance information are not distorted in the transmission system. Phase shift of the subcarrier in relation to the reference burst signal will cause hue shift, while nonlinearity in the system can result in variations of saturation and luminance. Color detail in a scene which produces color video frequencies up to approximately 1.2 mc must also be transmitted, and this coloring information can produce sideband frequencies 600 kc above the subcarrier. Therefore, frequencies as high as 4.18 mc above picture carrier must be transmitted with a minimum of frequency distortion.

$$E_m = E_Y' + \left[0.49(E_B' - E_Y')\sin \omega t + 0.88(E_R' - E_Y')\sin(\omega t + 90°)\right] \quad (1)$$

where-

$$\left[E_Y' = 0.30\,E_R' + 0.59\,E_G' + 0.11\,E_B'\right] \quad (2)$$

$$\boxed{\overline{E_{SC}} = \sqrt{\left[0.49(E_B' - E_Y')\right]^2 + \left[0.88(E_R' - E_Y')\right]^2}} \quad (3)$$

and

$$\alpha = \tan^{-1}\left[\frac{0.88(E_R' - E_Y')}{0.49(E_B' - E_Y')}\right] \quad (4)$$

$$\boxed{E_m = E_Y' + \overline{E_{SC}} \angle \alpha} \quad (5)$$

Fig. 1—NTSC equation.

NTSC Specifications for Phase and Amplitude of Subcarrier

For color difference frequencies below 500 kc the NTSC signal may be represented by (1) of Fig. 1 where E_R', E_G', E_B' represent the gamma corrected voltages existing in the red, green, and blue color video channels. These three voltages are adjusted to be equal when white is being transmitted. Equation (2) of Fig. 1 shows that the wide-band luminance signal (E_Y') is generated by adding the red, green, and blue signals together in accordance with the luminance contributions of each of the NTSC primary colors when mixed to produce white.

The signal is generally expressed in terms of the color video signals (I) and (Q) which are linear combinations of ($E_R' - E_Y'$) and ($E_B' - E_Y'$). The bandwidth assigned to the (I) signal prior to modulation on the color subcarrier is about 1.2 mc while that assigned to the (Q) signal is approximately 600 kc. Since the measure-

* Decimal classification: R583.4. Original manuscript received by the Institute, October 1, 1953.
† Philco Research Div., Philadelphia, Pa.

ments of phase and amplitude of the color subcarrier to be described in this paper are not concerned with transition effects the equation given in Fig. 1 is perfectly valid. Therefore, substitution in this equation of known voltages existing in the red, green, and blue video channels, makes it possible to calculate the values of the luminance signal, the phase of the color subcarrier, and the amplitude of the color subcarrier.

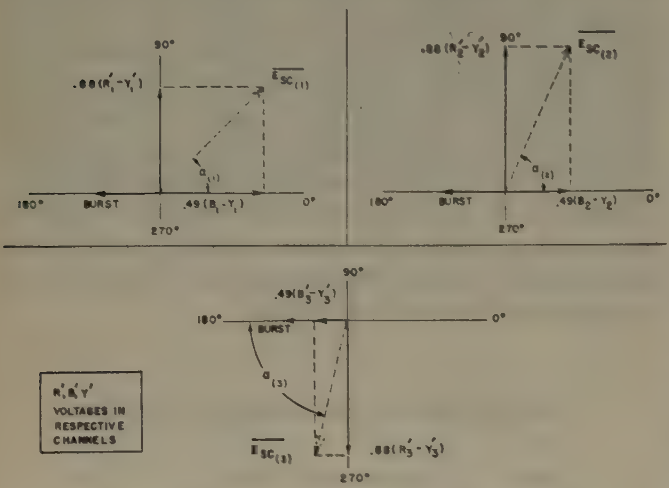


Fig. 2—Chrominance signal for three color samples.

Illustrated in Fig. 2 are three vector diagrams showing the phase and amplitude of the chrominance signal, which was previously referred to as the color subcarrier, when three different colors are being transmitted. The $(R-Y)$ video signal produces an amplitude modulated chrominance signal having a phase reference of 90 degrees, while the $(B-Y)$ video signal produces an amplitude modulated signal having a phase reference of 0 degree. The peak value of the chrominance signal produced by either modulator is directly proportional to the impressed video signal level, and the resultant chrominance signal is the vector sum of the output of the two modulators. Since the video voltages $(R-Y)$ and $(B-Y)$ have different values for different colors the chrominance signal is phase modulated even when the subcarrier phase of each modulator remains constant. This can be seen by comparing the phase of the chrominance signal $E_{sc(1)}$ and $E_{sc(2)}$ shown in Fig. 2. If the video signal impressed on either modulator becomes negative and swings below black level, which it does for a number of colors, the output phase of the subcarrier produced by that modulator is shifted 180 degrees. This is illustrated in Fig. 2 in which the phase of the subcarrier ($E_{sc(3)}$) is approximately 260 degrees for transmission of this particular color.[1]

Since the calibration of the equipment is specified in terms of an equation, a controlled NTSC color pilot signal may be generated by feeding the output signals from a color-bar generator into the input terminals of an encoder. The encoder is a device which accepts the individual red, green, and blue color video signals and packages them into the composite NTSC color video signal. The signals generated by the color-bar chart generator, as shown in Fig. 3, result in a reproduced color picture having nine vertical bars of black, red, yellow, green, cyan, gray, magenta, blue, and white. The individual primary colors and their complements are generated from 0.75-volt levels of signals in the respective color video channels. For instance red is produced by a 0.75 volt 5.8 μsec pulse following the black bar, while its complementary color cyan is produced from 0.75-volt pulse signals in the green and blue channels. The ninth bar is a peak white signal generated from one-volt levels of signals in the red, green, and blue channels.

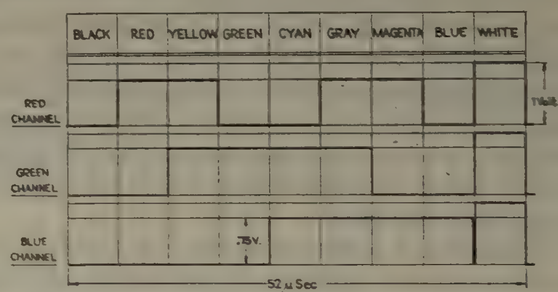


Fig. 3—Output signals from color bar generator.

Table I is a chart showing the video voltages existing at the output of the encoder when transmitting all the saturated colors and their complements at 75 per cent of full amplitude. When this signal, as shown in Fig. 4, is modulated on an rf picture carrier the modulation percentage is adjusted so that the peak white signal has

[1] J. F. Fisher, "Generation of NTSC color signals," Proc. I.R.E., vol. 41, p. 338; March, 1953.

TABLE I

CALIBRATION CHART

	Black	Red	Yellow	Green	Cyan	Gray	Magenta	Blue	White
E'_R	0	.75	.75	0	0	.75	.75	0	1.0
E'_G	0	0	.75	.75	.75	.75	0	0	1.0
E'_B	0	0	0	0	.75	.75	.75	.75	1.0
E'_Y	0	.22	.66	.44	.53	.75	.31	.09	1.0
E_{SC}	0	.47	.34	.44	.47	0	.44	.34	0
(θ) Referred to (B-y)	—	104°	167°	241°	284°	—	61°	347°	—

an rf amplitude of 12.5 per cent of peak carrier. The subcarrier peaks of yellow and cyan also produce video signals having excursions of one volt measured with respect to black level, since the composite video voltage is equal to the sum of the luminance signal plus the peak voltage of the subcarrier. Therefore, when using a color pilot signal of this type the transmitter is never called upon to modulate lower than 12.5 per cent of peak carrier. In some of the earlier NTSC tests color bars were generated from one-volt levels of signals in the respective color video channels, and if the white signal was set for 12.5 per cent of peak carrier level, to maintain normal fringe area reception, the signals generated from yellow and cyan bars (saturated colors at maximum luminance) would be clipped at a level where the transmitter reached zero per cent modulation.

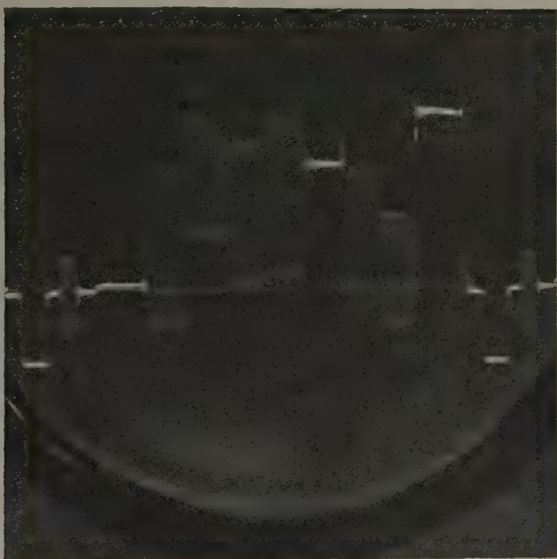


Fig. 4—Composite video (color bars).

Analysis of the color video signals produced by a flying spot scanner and a live color camera showed that saturated yellows and cyans at maximum luminance very seldom occur, and that a color pilot signal based on transmission of this information was much too stringent a test. A color pilot signal representing saturated primaries and their complements at 75 per cent of maximum amplitude is still a critical test, for very few colors in actual practice even approach this limit; furthermore, the pilot signal still provides a maximum modulation of 12.5 per cent when transmitting a bright white bar. Modulation of the transmitter to less than 12.5 per cent of peak carrier runs into very serious nonlinearity and phase shift problems, and should be avoided. The 12.5 per cent level of maximum modulation specified by the NTSC also protects the large percentage of television receivers in the field which employ intercarrier sound systems.

For these reasons, the NTSC has set the following system specifications for the transmission of the color-bar chart signal.

The angles of the subcarrier measured with respect to the burst phase, when reproducing saturated primaries and their complements at 75 per cent of full amplitude, shall be within ± 10 degrees and their amplitudes shall be within ± 20 per cent of the values specified in Table 1. Ratios of the measures amplitudes of the subcarrier to the luminance signal for the same saturated primaries and their complements shall fall between the limits of 0.8 and 1.2 of the values specified for their ratios.

Since the transmitter is only a part of the transmission system, which includes an encoder at the studio, and a link between the studio and transmitter, the tolerance is a system tolerance, and the transmitter should be adjusted to be well within these specifications.

Color Generating and Test Equipment

Performance measurements were made in the Philadelphia area using the transmitter of TV Station WPTZ which operates on Channel 3. At the time these measurements were taken the transmitter was an RCA type TT-5A with a rated power output of 5 kw visual and 2.5 kw aural. The station used an RCA Type TF-3A antenna, having a power gain of 4.9 db.

The Philco research color-signal generating equipment which includes a slide scanner, 35-mm flying spot color motion picture film scanner, color-bar chart generators, and encoders, is located in the Philco Research Division about six miles from the WPTZ transmitter. To broadcast signals originating from this equipment it was necessary to relay the color signals to the main transmitter, using an FM microwave link operating on a frequency of 7012 mc. Some of our original performance measurements were made involving this entire system. However, since the transmitter operating data were taken after program hours, between 1 a.m. and 6 a.m., it was found advantageous both from a manpower and operating basis to temporarily install duplicate color-signal generating and test equipment at the transmitter.

TABLE II

NTSC Equipment

Generating Equipment	Test Equipment
Sync. Gen.	Staircase Gen.
Color Bar Gen.	Freq. Burst Gen.
Encoder	Vectorimeter
3.58 mc Subcarrier Gen.	WM 12-A Receiver
Burst Keying Gen.	Wide-band Scope

Shown in the chart of Table II is a list of color generating and test equipment which was installed at the transmitter for these tests. It should be mentioned at this time that as a result of extensive tests with this equipment, a simplified procedure was developed that resulted in the transmission of certifiable NTSC color signals, involving less test equipment.

Since most of the equipment listed in Table II was developed especially for color television, and is not in common use, a brief description of some units follows.

Color-Bar Chart Generator

By means of keyed multivibrators, accurately timed pulse signals are generated and fed to the red, green, and blue input terminals of the encoder. These signals when viewed on a color display produce vertical bars of black, red, yellow, green, cyan, gray, magenta, blue, and white. The waveforms developed in the output channels of the color-bar chart generator were illustrated in Fig. 3.

Encoder

The encoder is a unit which accepts red, green, and blue video signals from any of the color video sources and packages them into the standard NTSC composite color video signal. Matrix circuits are included to derive the wide-band luminance signal from the proper proportions of E_R', E_G', and E_B', and additional matrix circuits are used to produce the narrow-band color difference signals. Balanced modulators to generate the chrominance signal, as well as delay networks to provide time coincidence between the luminance and chrominance signals are also included.

Color Subcarrier Generator

This unit generates the 3.579545-mc crystal controlled cw signal applied to the encoder. In addition, a 31.5 kc signal which is obtained from counter circuits is fed to the synchronizing generator to lock these units together. This insures that the color subcarrier is an odd multiple of one half the horizontal scanning frequency.

Burst Keying Generator

This generator produces a keying pulse which is fed to the encoder, and is used to key in the reference 3.58-mc sine-wave color sync signal, often referred to as the burst signal, during the back porch interval of the horizontal blanking period. This pulse is keyed out during the time the equalizing pulses and vertical sync are transmitted so that the 3.58-mc burst signal is not transmitted during this time.

Staircase Generator

This unit produces a ten-step linear staircase signal having a repetition rate of 15.75 kc. Standard blanking is included and provision is made for fading in a sync signal. For some of the transmitter measurements it is desirable to have a constant phase 3.58-mc signal averaged around each step of the staircase signal, and circuits for accomplishing this are included.

Frequency Burst Generator

By means of gated oscillators bursts of sine waves at frequencies of 500 kc, 1 mc, 2 mc, 3 mc, 4 mc, 5 mc occurring one after the other in a period of 52 μsec are generated. The use of gated oscillators results in the sine-wave bursts remaining stationary when viewed on an oscilloscope operating at a line repetition rate of 15.75 kc. Standard blanking is included, and provision is also made for fading in a mixed synchronizing signal. Since the generator produces a composite video signal with standard blanking and synchronizing signals it is very useful for checking the over-all frequency response of television apparatus.

Keyed clamps which derive their keying pulses from the horizontal synchronizing pulses of a composite video signal, and clamp black level during the back porch interval, are widely used in television transmission equipment. Measurements may be made using the frequency burst generator without disconnecting the clamp circuits, and therefore provides an accurate and speedy method of checking the over-all frequency response of television apparatus and transmission systems.

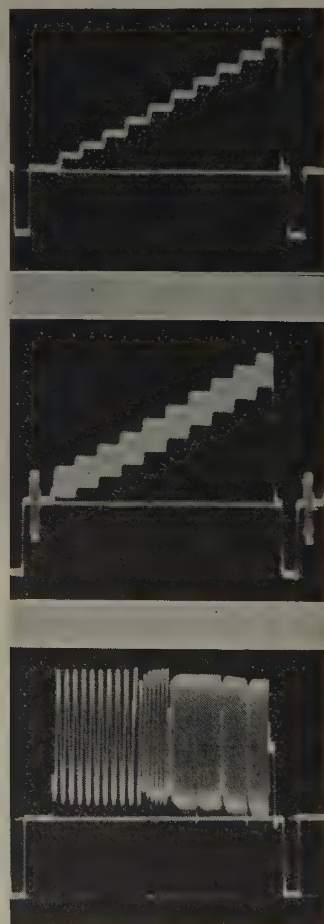


Fig. 5—Composite picture (burst gen., staircase, staircase and (3.58 mc).

Fig. 5 is a composite picture of the output signals produced by the staircase generator and the frequency burst generator.

Vectorimeter

The vectorimeter provides a polar display of the chrominance signal indicating both the phase and amplitude of the color subcarrier. Its circuits include a

chrominance signal filter, an oscillator locked in phase to the burst signal, and two synchronous demodulators. The output signals from the synchronous demodulators, which are the color difference video signals $(E_R'-E_Y')$ and $(E_B'-E_Y')$, are fed to the horizontal and vertical plates of an oscilloscope to produce a polar display. The vectorimeter when used at a number of locations in the transmission system provides a fast and accurate method for test and alignment when a color-bar chart pilot signal is transmitted over the system. The phase and amplitude of the chrominance signals produced by each color of the color-bar chart signal may be viewed simultaneously and only a few seconds is required for an operating engineer to determine how well the system is transmitting the chrominance information. Fig. 6 is a photograph of a portable vectorimeter we have developed for color transmission tests.

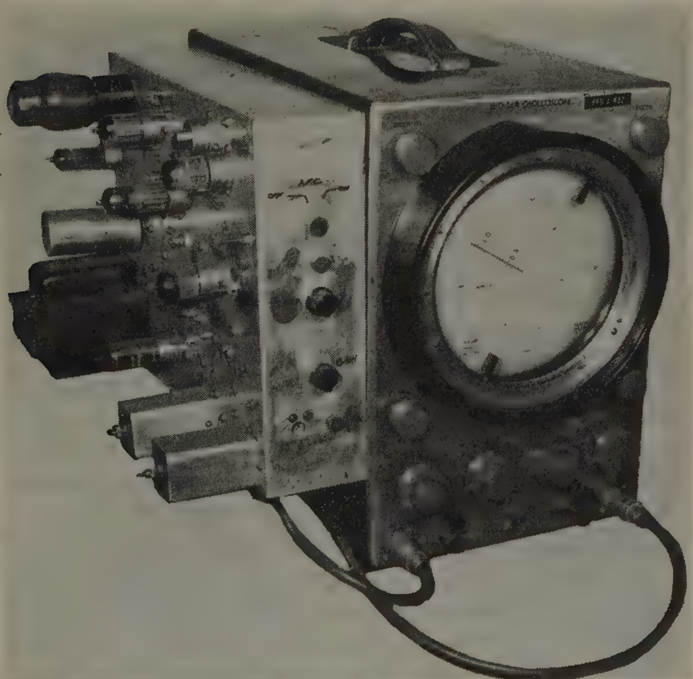


Fig. 6—Photograph of portable vectorimeter.

Shown in Fig. 7 is a view of the calibration mask and moveable cursor used on the vectorimeter. The phase and amplitude of the color subcarrier are indicated by a dot of light from the cathode-ray tube. The phase of the subcarrier is displayed around the circumference, while the distance from the center of the diagram to the vector tip (dot of light) is equal to the peak value of the subcarrier. The square enclosures around each color point are about one half the NTSC system tolerance.

Performance Measurement

It was known from some of our previous tests that the modulation characteristic of the transmitter was "*S*" shaped, and that ordinary stabilizing amplifiers could not be used for color operation.

In consulting with the manufacturer, it was learned that the RCA stabilizing amplifier (Type TA5B) could be used for color operation with certain design changes,

Fig. 7—Photograph of vectorimeter mask.

and that correcting networks could be incorporated in this amplifier to linearize the modulation characteristic of the main transmitter. A circuit diagram of a portion of this amplifier is shown in Fig. 8. The major design

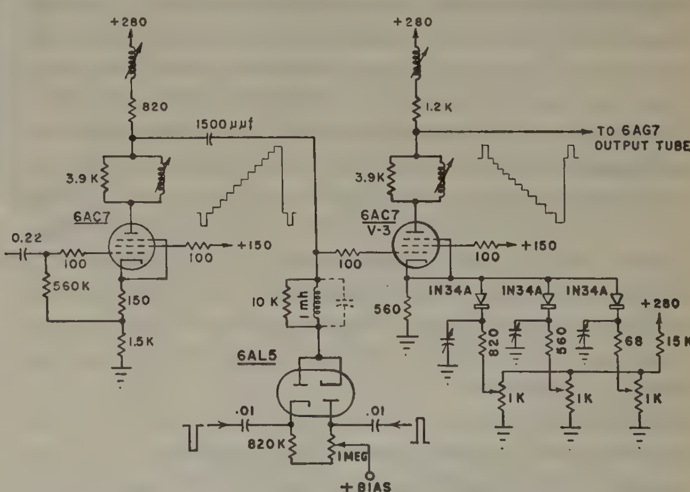


Fig. 8—Circuit diagram of color stabilizing amp.

changes involved connecting a 3.58-mc resonant circuit between the clamping diodes and the grid circuit of V-3 to minimize any disturbance to the phase or amplitude of the burst signal by the clamping pulses. In addition to this, three crystals, returned to variable voltages, were connected across the cathode resistor of

tube V-3, to provide white stretch. Since the keyed clamp operates during the back porch interval of the video signal to establish black level at a definite dc voltage on the grid of V-3, black level will also be maintained at a constant dc voltage at the cathode of V-3. The dc voltage applied to the crystals may be adjusted so they will conduct at different video levels, and alter the gain of V-3 by changing the value of the cathode degenerative resistor. In this manner white stretch can be applied to compensate for the white compression of the transmitter modulator.

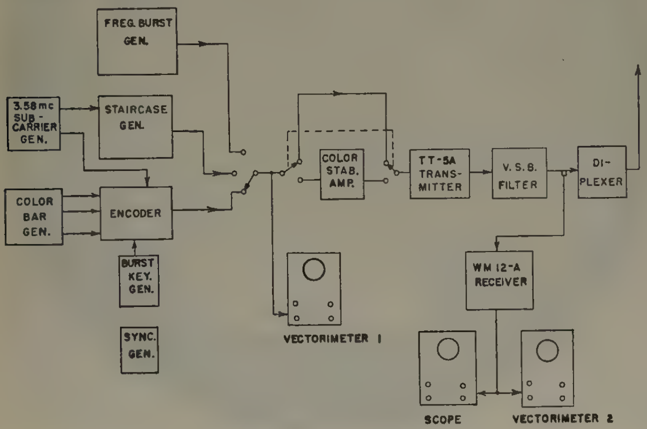


Fig. 9—Block diagram of equipment layout.

The color generating and test equipment was connected, as illustrated in Fig. 9, with the output of the encoder connected to the input terminals of the transmitter. A probe inserted in the antenna feed line, between the vestigial sideband filter and the diplexer, was connected to the input of an RCA WM12A monitoring receiver. The transmitter was adjusted for a modulation of 12.5 per cent of peak carrier on the white bar of the color-bar chart signal. A vectorimeter connected to the output of the WM12A receiver was used to observe the phase and amplitude of the subcarrier when a standard color-bar chart signal of all the primary colors and their complements was transmitted. Although the phase of all colors was within ±10 degrees of its calculated value, the amplitude of the subcarrier for colors such as yellow and cyan, in which the peak of the subcarrier extends to 12.5 per cent modulation, was badly compressed.

A staircase signal, including sync, was then fed into the input of the color stabilizing amplifier. The white stretch diodes were biased off, and the voltage between black level and peak white was adjusted to a one-volt level at the output of the color stabilizing amplifier, by means of the input gain control. The output of the color stabilizing amplifier was connected to the input terminals of the transmitter and the master gain control on the transmitter was adjusted for a modulation of 12.5 per cent of peak carrier at white level. Since the transmitter also compresses the sync signal, the level of this signal was increased at the output of the staircase generator to provide an rf envelope in which black level was set at 75 per cent of peak carrier.

A Tektronix Model 524 oscilloscope was connected to the output of the WM12A receiver and the probe in the transmission line was twisted to obtain a 1-v signal (black to white) at the output of the WM12A. The scope presentation showed crushing of the upper steps (near white) of the staircase signal. By simultaneous adjustment of the stabilizing amplifier gain, and applying the dc voltages to the white stretch diodes, the staircase signal was linearized at the output of the WM12A receiver and held to the same one-volt level which represented a modulation of 12.5 per cent of peak rf carrier at white level. All three white stretch diodes were needed to accomplish this. The procedure followed was to use the "softest" diodes first to correct the crushing nearest black level. This adjustment of the color stabilizing amplifier compensated for the low-frequency nonlinearity of the transmitter.

The standard color-bar chart signal was then applied to the input of the stabilizing amplifier from the encoder and adjusted so the peak white bar had an amplitude of 1 v peak to peak (black to white) at the output of the color stabilizing amplifier. This signal level resulted in a modulation of 12.5 per cent of peak carrier at white level. Vectorimeter readings of phase and amplitude of the color subcarrier were then taken at the input of the color stabilizing amplifier and the output of the WM12A. This data is recorded in Table III and shows the transmitter was adjusted to operate well within NTSC tolerances.

TABLE III

DATA (INPUT AND OUTPUT)

Chrominance Amplitude				Chrominance Phase		
Input to Stab. Amp.	Transmitter Output	% Difference	Color	Input to Stab. Amp.	Transmitter Output	Phase Difference
1.00	1.00	—	Red	108°	110°	+2°
.75	.68	−9%	Yellow	172°	173°	+1°
.96	.95	−1%	Green	241°	243°	+2°
1.00	.94	−6%	Cyan	284°	286°	+2°
.67	.71	+6%	Blue	353°	353°	—
.94	.90	−4%	Magenta	65°	68°	+3°
.50	.50	—	Burst	180°	180°	—

A different type test signal was then applied to the input of the transmitter from the color stabilizing amplifier, which consisted of a 0.75 volt 10-step staircase signal to which was added a 0.25 volt peak 3.58-mc constant phase sine-wave signal averaged around each step. This signal was observed with a vectorimeter at the output of the WM12A receiver, and the phase of the subcarrier at each of the ten operating levels was within ±5 degrees, while the amplitude was within ±8 per cent.

A test signal of this type can be used to simultaneously check the low-frequency linearity, phase shift of the subcarrier with respect to the burst at ten quantized video levels, and also the incremental gain at 3.58 mc.

For checking low-frequency linearity the output of the WM12A monitoring receiver is connected to the input terminals of an oscilloscope through a low pass filter which removes the chrominance signal. Linear operation will produce an oscilloscope display in which all steps of the staircase signal are the same height.

The incremental gain at 3.58 mc may be measured by connecting the output of the WM12A to the input of the oscilloscope through a high pass filter which removes the luminance signal and passes the chrominance signal. When this signal is displayed on an oscilloscope operating at a 15.75-kc repetition rate, the resultant levels of the 3.58-mc signal at each quantized step are displayed along the "X" axis. If these signals are all the same amplitude the incremental gain at each level is the same.

The phase shift of the 3.58-mc color subcarrier may be readily measured with a vectorimeter connected to the output of the WM12A receiver. Relative phase shift of the 3.58-mc signal at any of the ten quantized levels will show as vector dots not falling on a straight line which connects the outermost vector dot with the center of the display. The incremental gain at 3.58 mc may also be checked with the vectorimeter, and if the incremental gain at all quantized levels is the same, all the vector dots will be located at the same radial distance from the center of the display. If there is no relative phase shift, and the incremental gain at all quantized levels is the same, all the vector dots will fall on top of each other.

Measurements made on this particular transmitter indicated that if the system was linearized on a staircase signal of the type just described, a certifiable NTSC color signal could be radiated in as far as amplitude of the luminance signal and phase and amplitude of the chrominance signal was concerned. On subsequent experimental color transmissions, which included an official field test for Panel 16 of the NTSC, this procedure was followed and produced good results. On this basis it would seem that the following equipment which includes a staircase generator, vectorimeter, and wideband oscilloscope installed at the transmitter would provide the necessary tools for alignment.

Additional Transmitter Specifications

Frequency Response

As mentioned earlier, the color subcarrier is both phase and amplitude modulated and as such contains sidebands 600 kc above and 1.2 mc below the subcarrier frequency of 3.58 mc. To prevent the attenuation of this coloring information and to provide an excellent luminance signal the NTSC has established the following specification for the over-all frequency response of the transmitter.

A sine wave of 3.58 mc introduced at those terminals of the transmitter which are normally fed the color picture signal shall produce a radiated signal having an amplitude (as measured with a diode on the rf transmission line supplying power to the antenna) which is down (6 ± 2) db with respect to a radiated signal produced by a sine wave of 200 kc. In addition, the amplitude of the radiated signal shall not vary more than ± 2 db between the modulating frequencies of 2.1 and 4.18 mc.

This means that the transmitter should be adjusted to have an equivalent over-all frequency response, when measured with a wide-band monitoring receiver in which picture carrier is located at the 50 per cent response point, within ± 2 db between the frequencies of 60 cycles and 4.18 mc.

With the transmitter left in normal operating condition, measurements were made of the over-all frequency response using the burst frequency generator. A diode probe assembly inserted in the rf transmission line was connected to the input terminals of a Tektronix Model 524 oscilloscope to obtain this data. The measured overall frequency response of WPTZ was within NTSC specifications.

Sound Transmitter

To minimize the 920-kc beat between sound carrier and color subcarrier the NTSC has established two specifications.

First, the effective radiated power of the aural-signal transmitter shall not be more than 70 per cent nor less than 50 per cent of the peak power of the visual signal transmitter.

Second, the frequency of the unmodulated sound carrier shall be 4.5 mc ± 1000 cycles above the frequency actually in use for the picture carrier.

Measurements to insure conformity with these specifications may be obtained from standard equipment and therefore will not be described.

Envelope Delay Correction

To improve the reproduced transitions on color edges as well as to improve the transient response of the luminance signal, the NTSC has established specifications on the envelope delay of the transmitter.

The correcting network is an all pass circuit having a flat frequency response and an envelope delay suitable to correct for the envelope delay inherent in the rf and IF circuits of an average television receiver. Inclusion of such a network tends to make the over-all system, which includes transmitter and receiver, a linear phase system, and as pointed out by Kell and Fredendall[2] also improves the transient response of monochrome signals received on existing black and white receivers.

Out of Channel Radiation

The NTSC has specified that out of channel radiation should be at least 60 db below the peak picture

[2] R. D. Kell and G. L. Fredendall, "Standardization of the transient response of television transmitters," *RCA Review*, vol. X, p. 17; March, 1949.

level. When the 3.58-mc subcarrier is modulated on the rf picture carrier an upper and lower sideband signal is generated. The lower sideband falls in the lower adjacent television channel and an extra notch filter will have to be provided to meet the 60-db figure.

Both the envelope delay corrector and the lower adjacent channel subcarrier notch filter will certainly be available from TV broadcast equipment manufacturers in the near future.

Conclusions

On the basis of tests with this particular transmitter it would seem that the adoption of NTSC color standards will not require any major modifications to a standard monochrome transmitter. The test equipment which includes a wide-band oscilloscope, a staircase generator, and vectorimeter should be available to align the color stabilizing amplifier and transmitter.

It should be mentioned again that many of the stabilizing amplifiers used in TV broadcast stations will not handle the NTSC signal satisfactorily without design changes. The envelope delay corrector and the lower adjacent channel notch filter, being passive networks, should require very little adjustment, and once installed could be used for both monochrome and color transmissions. In addition most transmitters when properly aligned have an over-all frequency response within NTSC specifications.

Transmission of Color Over Inter-City Television Networks*

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Summary—**The advent of television broadcasting in color, in accordance with the standards proposed by the NTSC, will require the application of new techniques and instrumentalities to the network channels which transmit television signals throughout the country. The extent of today's television networks and their continuing growth makes this a job of considerable magnitude.**

The transmission requirements of NTSC color signals are more stringent than those of monochrome, because additional information is carried in the same video frequency band. The need for closer control is at the upper end of the video frequency band, where the color subcarrier is placed. It appears that additional gain and delay equalizers will be required on all channels and periodic tests and adjustments will have to be substantially increased. On coaxial cable systems, special frequency translators will be needed to shift the color information to frequencies within the coaxial passband.

Introduction

REGULAR commercial broadcasting of color television in accordance with the specifications formulated by the National Television System Committee appears to be just around the corner, and may already be here by the time this article appears in print. This has presented a challenge to the Bell System, which furnishes monochrome video channels for all the major television broadcasting networks of the United States, and for theatre and other "closed circuit" television transmissions as well, to develop and apply whatever new techniques and instrumentalities are needed to make these channels suitable for transmission of NTSC color. It is the purpose of this article to describe some of the measures proposed for this purpose, and to give some idea of the magnitude of the job of applying them to today's extensive and growing television networks.

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Extent of Video Networks

Regular inter-city television transmission service was inaugurated by the Bell System on May 1, 1948. At that time the facilities available for service consisted of one radio relay channel in each direction between New York and Boston, and one coaxial cable channel in each direction between New York and Washington, a total of about 900 channel miles. Growth since that time has been at a high rate as television channels have expanded across the United States and into Canada. At the end of August, 1953, more than 38,000 miles of inter-city channels for monochrome television were in service, and it is estimated that by the end of 1953 the total will be more than 45,000 miles, routed approximately as shown in Fig. 1. Of this total about 27,000 miles will be on radio relay systems and 18,000 miles in cables. The growth is still continuing; 15,000 channel miles of the above facilities were provided during 1953, and it is expected that a like mileage will be added during 1954. In addition to inter-city channels there are, of course, many miles of local channels, both cable and radio, which furnish connections between the network terminal telephone offices in various cities and the broadcasters' control rooms, and between control rooms, studios, remote pickup points and broadcast transmitting stations.

Network Transmission Requirements

The basic requirement for video transmission of either monochrome or color is that the facility be capable of transmitting the broad range of frequencies required, with noise and distortion held within appropriate limits. Coaxial cable and radio relay channels, that in ordinary telephone use carry hundreds of message circuits, are generally capable of meeting this requirement.

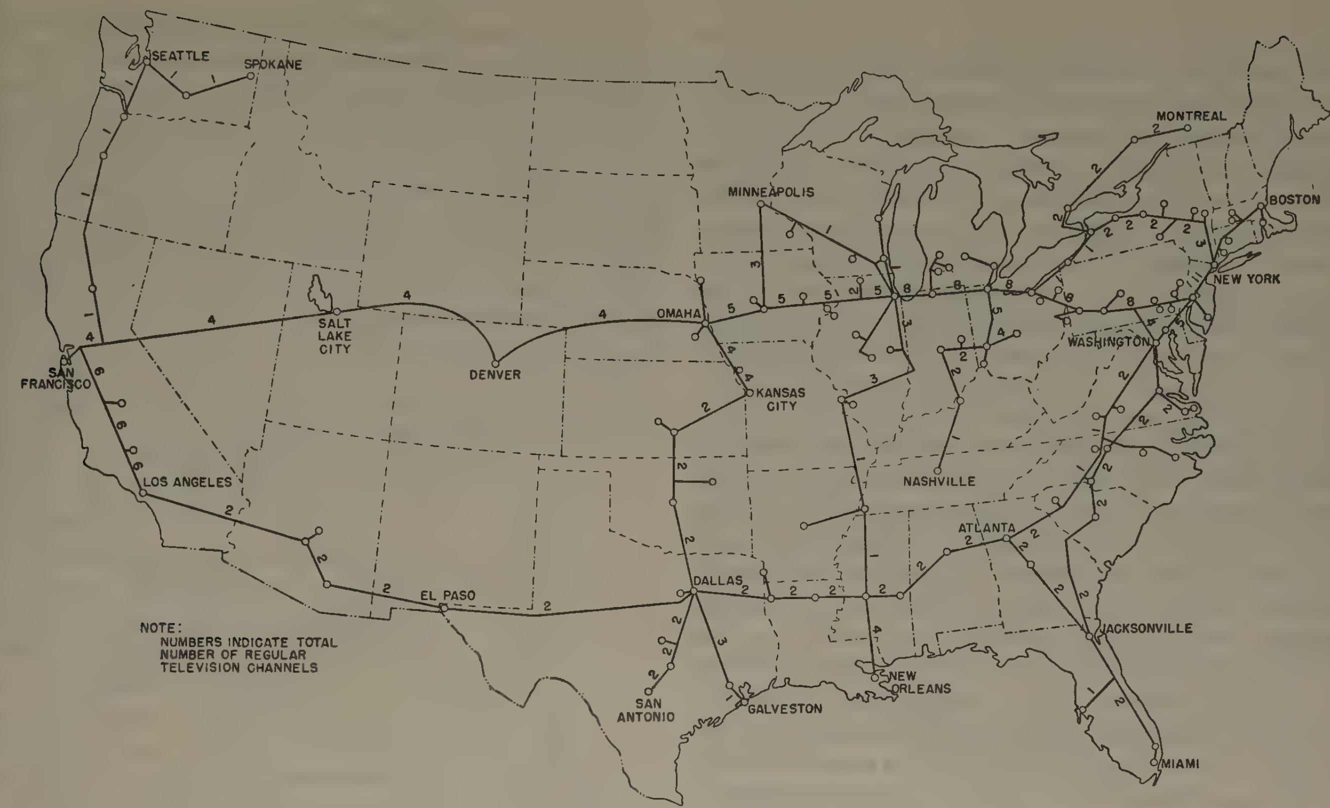

Fig. 1—Expected layout of Bell System inter-city video channels at end of 1953.

The detailed technical problems of providing satisfactory video transmissions over inter-city facilities stem principally from the large numbers of individual units which must be used to cover the great distances involved. While it may be reasonably easy to design and maintain systems which will provide adequate transmission through two or three amplifiers in tandem, the difficulties increase with distance and numbers of units. In the nation-wide television networks it is required that several hundred amplifiers be operated in tandem. With numbers of this order it becomes a very real problem to design and build each item of plant to the necessary accuracy, and to provide sufficiently close maintenance adjustments to furnish consistently satisfactory over-all transmission despite variations caused by temperature changes, vacuum-tube aging, and other factors.

The transmission problem is further complicated by requirements for drop-off points en route and for network switching. The transmission must be satisfactory to every station along the route and its branches, as well as to the ultimate terminal. It is also frequently necessary to perform switches which rearrange the various network sections into different combinations. For example, a customer may order one of the channels transmitting southward from Omaha be fed from a westbound transcontinental channel for one program and then quickly switched to feed from an eastbound channel for the succeeding program; or a section of network such as Omaha-Denver may develop trouble, in which case a standby channel may be switched in to replace the defective channel. To permit station connections and switches at intermediate points, the characteristics of networks must not only be adjusted for satisfactory over-all transmission, but in addition each individual section of the networks must be accurately and uniformly equalized so as to be interchangeable with any other.

On network sections consisting of radio relay facilities, switching is usually performed at the intermediate frequency (IF) of the radio equipment, to avoid the accumulation of small distortions which would result from demodulating to the video base-band and then remodulating back to radio frequencies at every switching point. This makes it desirable that all channels be uniformly equalized across the IF frequency band, rather than equalizing by the generally simpler expedient of applying mop-up equalizers after the signal has been reconverted to video frequencies.

Requirements for Color Transmission

Network channels which are perfectly satisfactory for monochrome transmission are not necessarily suitable for transmission of NTSC color signals. The color signal consists essentially of the same luminance signal as in monochrome television, plus color information which is transmitted by modulation of a subcarrier of 3.579545 mc inserted near the upper end of the video band. (In this article the frequency of the color subcarrier will hereafter be referred to as 3.6 mc.) The result is that considerably more information is packed into the frequency band than in the case of monochrome signals,

and it is only natural that the transmission medium must meet more stringent requirements.

In monochrome signals the major portion of the transmitted energy is at the lower end of the video frequency range. The high-frequency end of the video band carries only fine detail, the energy content of which is relatively low. It follows that transmission requirements are most severe for the lower frequencies. In the range below one mc or so, especially, it is important that the amplitude response be flat within a few tenths of a db, and that delay distortion be kept within a small fraction of a μsec. Permissible tolerances increase at the higher frequencies. Rounding off of the amplitude response in the 3- to 4-mc range, for example, is hardly perceptible. In fact, many home television receivers are almost insensitive to impulses much above 3 mc. These requirements of monochrome transmission coincide very nicely with the natural capabilities of network facilities which are inherently easier to equalize and maintain within close limits at the low frequencies than at the high.

With the insertion of color information carried by the 3.6-mc subcarrier, this condition no longer obtains. In addition to the requirement for accurate equalization at the lower frequencies, which remains unchanged, it now becomes necessary to place stringent limitations on amplitude and delay variations at the upper end of the video band as well.

The information transmitted by the 3.6-mc carrier determines the hue and saturation of colors in the reproduced picture. To express both these characteristics the carrier is both amplitude and phase modulated; essentially, the amplitude modulation expresses the saturation, and the phase modulation expresses hue. Not only must both of these modulations be transmitted faithfully, but the color information must also be maintained in exact synchronism with the luminance information carried by the low frequencies. This necessitates uniform amplitude and delay response across the entire video frequency band.

Possibly the most difficult requirement of the NTSC signal, from the standpoint of network transmission, is the very rigid restriction of permissible phase shift at 3.6 mc for varying levels of luminance. The hue of the received color at any point in the picture is determined by the difference in phase between the color carrier representing that point, and a reference burst of 3.6 mc sent out during the "back porch" portion of the horizontal blanking interval. It follows that if the phase shift of the network facilities at 3.6 mc is not virtually the same for all luminance levels, from blanking to white, misrepresentation of some hues will result. The maximum tolerable change of phase with luminance, or "differential phase shift," is believed to be in the order of 5 degrees. Expressed in terms of time delay, this amounts to only 0.004 μsec, which is more than ten times as critical as the delay distortion requirement for good picture definition and proper registration.

An interesting illustration of differential phase shift on Type TD-2 radio relay facilities is shown in Fig. 2. This figure shows an envelope delay characteristic of a TD-2 radio relay channel from IF input to IF output. (This illustration should not be regarded as typical since many other shapes may be found.) Frequency modulation is used to raise the video signals to the IF band. A swing of 8 mc is used with the tips of the sync pulses clamped at 74 mc, and white level falling at 66 mc. The resulting position of the video signal in the IF band is shown in Fig. 2.

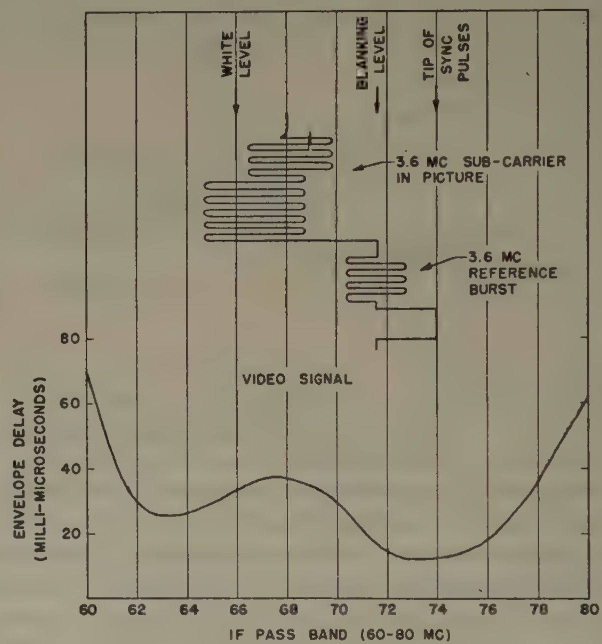

Fig. 2—Illustrative envelope delay curve of a TD-2 radio relay channel from IF input to IF output, and normal position of the video signal in the IF band.

In the case illustrated, although the delay distortion shown would be well within requirements for good resolution and registration, the differences in delay between the 3.6-mc reference burst introduced at blanking level and the 3.6-mc color carrier superimposed at various luminance levels would result in undesirable hue shift.

Adaptation of Networks for Color

It is evident that special measures will be required to adapt existing network channels for color transmissions. On radio relay facilities these will take the form of additional amplitude and delay equalization to provide closer control in the region of the color subcarrier, and measures to keep differential phase shift of the color carrier within satisfactory bounds.

On most of the coaxial cable facilities in use today, not only will additional equalization measures be needed, but it will also be necessary to provide instrumentalities to enable the color information to be transmitted within the pass band of the coaxial facilities.

Translation of Signals to Coaxial Frequency Range

The coaxial cable facilities at present in use on television networks are known as Type L1 and are capable of transmitting a video band up to about 2.7 mc. Transmission of standard NTSC color signals over such a coaxial channel, therefore, results in stripping off the color information so that the output signal is monochrome only.

To adapt coaxial cable facilities for transmission of NTSC color signals, it is planned to use converter units at both transmitting and receiving terminals of coaxial sections, which will, respectively, translate the color signal into the range accepted by the coaxial, and subsequently restore it to its normal frequency range. This will be done by dividing the original signal into a luminance component and a color component by means of filters. The luminance component will comprise the frequency band below about 2 mc, while the color component will include a frequency band from about 3.3 to 4.0 mc. In transmission over coaxial facilities the color component will be shifted to a frequency band corresponding to video frequencies of 2.0 to 2.6 mc. At receiving terminals the color information will be translated back to its original position in the video frequency band. It is important, of course, that uniform gain and delay response be maintained throughout and that at the conclusion of these frequency translations the color carrier be restored exactly to its original frequency.

Another coaxial cable carrier system, designated L3, has been developed recently. With this system each coaxial tube passes a frequency band approximately 8 mc wide and is capable of handling 1,800 message channels or 600 message channels and one television channel of full 4-mc bandwidth. Television channels provided by means of L3 carrier systems will be capable of transmitting NTSC color signals without necessity for translating devices.

Test Equipment

In addition to the new equalizers and other circuit elements required to make television channels suitable for color, a number of new items of test equipment are needed to enable proper adjustment of the variable elements, and to insure that the networks are in satisfactory operating condition. To measure and adjust differential phase shift, for example, some entirely new test equipment has been developed and will have to be provided at all network terminals, junctions, and switching points. It also appears desirable to provide faster means of measuring gain-frequency and delay-frequency characteristics to minimize the time necessary to make these measurements, in view of the expected increase in the frequency at which they will have to be made. Color monitors will also be provided at terminal and junction points to check the quality of transmissions.

Maintenance and Service Operation

Proper maintenance and operation of television networks is, of course, essential for satisfactory service results. Experience in handling experimental color transmissions thus far indicates that there will have to be a substantial increase in maintenance effort over that necessary on monochrome channels to keep the video channels lined up suitably for color. It also appears necessary to provide for more intensive monitoring of color programs during service, in order to detect immediately any detrimental effects of small changes in transmission conditions and take steps to compensate for them.

Conclusion

From the foregoing it may be seen that the job of conditioning the thousands of miles of existing and planned television networks for satisfactory color transmission is a project of considerable magnitude. New techniques and new instrumentalities are being developed, both to modify the network characteristics as required for color, and to measure and adjust the resultant characteristics. Substantial progress has already been made in this regard.

The remaining job is to provide and install the new devices in sufficient quantity to satisfy the requirements of the widespread networks and to apply the necessary trained manpower to keep them properly adjusted. Similar problems have been encountered in the past in setting up the original television channels and carrying out the subsequent expansion. That they were satisfactorily solved is evidenced by the quality of monochrome transmission on today's nation-wide networks. We can confidently expect that the problems of color transmission will be solved in the same satisfactory manner.

Improving the Transient Response of Television Receivers*

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Summary—Larger kinescopes and the advent of compatible color television have given increased importance to the problem of improving the transient response of television receivers. This paper is concerned with receiver design factors that make for improved electrical fidelity, although the interlocking nature of the transmitter and receiver requires some consideration of the transmitter aspects of the problem. In the receiver, the electrical fidelity is primarily determined by the delay distortion produced in the video IF amplifier, and the extent to which this distortion is compensated in the peaking circuits of the video detector and the video amplifier. Optimum results are obtained by working with both the phase-delay characteristic of the over-all receiver and the corresponding amplitude characteristic.

In color receivers, prevention of delay distortion has been found to be of primary importance, as might be expected from the fact that the channel is being used to greater capacity. The factors which determine cross talk between the I and Q color-difference signals and coincidence of the luminance and chrominance information are described.

Ultimately, obtaining a uniformly high standard of receiver transient response depends upon industry agreement on a standard monitor. Widespread use of a standard monitor should go far toward eliminating the present tendency for receiver designers to vary their designs to meet the peculiarities of particular transmitters.

General Considerations

THE response of a receiver may be evaluated by examining its response to the two test wave forms shown in Fig. 1. These transient wave forms are made up of frequency components which range from zero frequency to 4.5 mc, the exact form of the spectrum varying with the particular transient. For example, the frequency spectrum of the step transition has an amplitude that varies inversely as the frequency, while the spectrum corresponding to a steady-state wedge pattern is made up of only discrete harmonics of the fundamental.

This viewpoint of going from the time domain to the frequency domain, as in Fig. 1, points up the need for transmitting the frequency spectrum making up the transient so that all components arrive at the output with the same time delay and the same relative amplitude. In the minimum phase-shift networks which are commonly employed in the IF and video circuits of television receivers, the phase response of the network is uniquely defined once the amplitude response of the network is fixed. Aside from the use of nonminimum phase-shift networks, a more favorable delay characteristic can therefore be obtained only by distortion of the amplitude response. As can be seen intuitively, it is more important that the relative delays of the individual spectrum components be the same, than it is that their relative amplitudes be closely preserved. For this reason it is usually desirable to distort the amplitude response to make the phase delay more constant.

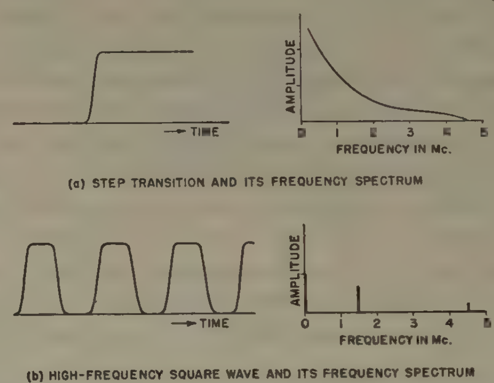

Fig. 1—The transient response of a television receiver may be evaluated by its response to the two idealized wave forms. The corresponding frequency spectra of these wave forms are shown.

It is apparent from Fig. 1 that the reproduction of a step change in brightness requires that uniform time delay be maintained over a very wide range of frequencies, from a few tenths of a megacycle to 4.5 mc. Reproduction of good wedge detail, however, is much less difficult; here only a few harmonics combine to form the wedge and uniformity of delay is required over a narrower band of frequencies. In the limit, wedge detail corresponding to greater than a 100-line resolution is reproduced as a single sinusoidal component and good reproduction is obtained even though the delay characteristic of the circuit may be non-uniform and the unit step response correspondingly poor.

It is unfortunate that good resolution is so often advanced as being a criterion of transient response. Taken alone, the ability to resolve the vertical wedges of a test pattern is an exceedingly poor measure of transient response and is much inferior to the unit step characteristic, which shows up the presence or absence of smear, preshoot, overshoot, and ringing.

Phase and Envelope Delay

The electrical fidelity of a television receiver may conveniently be measured by comparing the video output at the kinescope grid with the video input at the transmitter modulator. This permits the substitution of a low-pass filter for the relatively complex RF-IF detector-video structure of the television receiver. In

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general, however, the equivalent response so determined will be dependent upon both the per cent modulation and the exact wave form of the input.[1] Fortunately, for a receiver having approximately constant time delay, the response to the maximum 5 to 1 change from black-to-white does not differ appreciably from the response to low-per cent modulation. It is therefore valid to consider the equivalent response corresponding to low-per cent modulation as being indicative of receiver performance. This equivalent video response may be determined by sinusoidally modulating the transmitter and noting the amplitude and phase of the corresponding video at the kinescope grid.[2] In this manner, the phase vs. frequency and the amplitude vs. frequency curves shown in Fig. 2 may be determined.

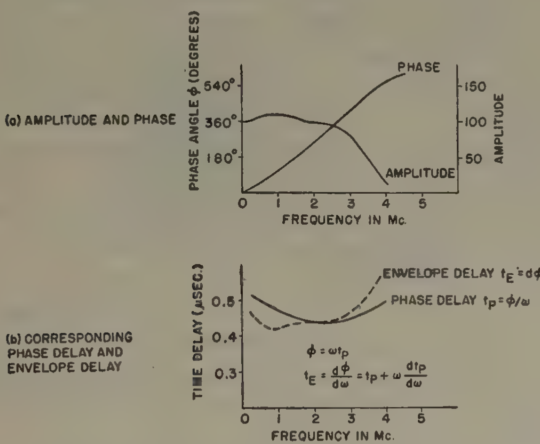


Fig. 2—Typical curves to illustrate the relation between amplitude, phase angle, phase delay and envelope delay.

Various methods are used for evaluating the uniformity of transmission time through a television receiver. These refer to the equivalent video response and include:

(a) Plotting phase angle against frequency
(b) Plotting phase delay $t_P = \phi/\omega$ against frequency
(c) Plotting envelope time delay $t_E = d\phi/d\omega$ against frequency.[3]

The first method is straightforward. However, the phase angle curve (Fig. 2a) is difficult to interpret because small changes in the slope cause large changes in the relative phase delay.

This difficulty can be partially overcome by plotting the phase delay vs. frequency as in Fig. 2b. This delay curve is relatively easy to evaluate since deviations from the "average" delay can be interpreted in comparison with the rise time of the circuit.

The third method used for evaluating the phase distortion of the output video signal is to plot the envelope delay $t_E = d\phi/d\omega$ vs. frequency. This frequently is plotted by taking the slope of the phase angle ϕ vs. frequency curve. More accurately, the envelope delay can be determined from the phase delay as follows: Since

$$\text{phase delay} = t_P = \frac{\phi}{\omega}$$

$$\phi = \omega t_P$$

$$\therefore \quad \text{envelope delay} = t_E = \frac{d\phi}{d\omega} = t_P + \omega \frac{dt_P}{d\omega}. \quad (1)$$

Thus the envelope delay is equal to the phase delay plus a term which takes into account how rapidly the phase delay varies with frequency.

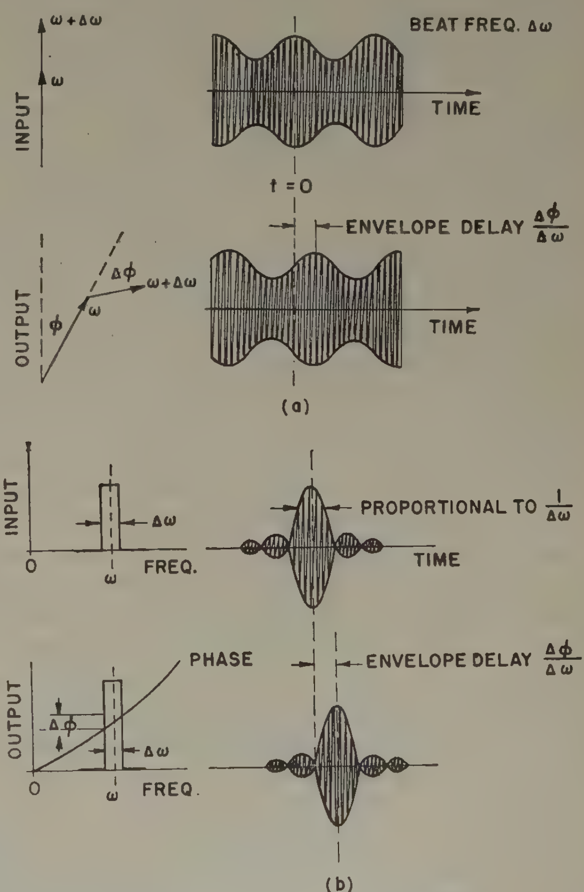


Fig. 3—Envelope delay may be interpreted as (a) the delay of the low-frequency envelope formed by ω and $\omega+\Delta\omega$, or as (b) the delay of the envelope formed by a spectrum interval $\Delta\omega$ wide.

The envelope delay of a video signal may be measured, as shown in Fig. 3, by taking two frequencies close together and noting that they form a low-frequency envelope. For example, 3 mc and 3.1 mc beat to form a 3 mc signal the envelope of which varies at a 100 kc rate. The envelope delay $d\phi/d\omega$ then represents the de-

[1] For a general discussion of the equivalent video response of a vestigial sideband system see: E. C. Cherry, "Transmission characteristics of asymmetrical sideband communication networks," *Jour. of the IEE*, vol. 89, p. 19; 1942, and vol. 90, p. 75; 1943.

[2] This response may also be determined if the response of the receiver to a step function is known. For a graphic procedure see: A. V. Bedford, and G. L. Fredendall, "Analysis, synthesis, and evaluation of the transient response of television amplifiers," Proc. I.R.E., vol. 30, pp. 440–457; October, 1942.

[3] This definition of envelope delay conforms with I.R.E. standards. It differs, however, from that used by some authors, e.g., F. E. Terman, "Radio Engineers Handbook," p. 141; 1943, where envelope delay is defined in reference to a carrier as $\Delta\phi/\Delta\omega$. Envelope delay is often referred to as group delay.

lay of this low-frequency envelope. In the classical case, rather than taking just two frequencies, a spectrum interval $\Delta\omega$ wide is taken to form a "low-frequency" wave packet; the envelope delay is then the delay of this low-frequency pulse.

The use of envelope delay in the analysis of television receiver distortion has probably received its impetus from the questionable concept that the transient response corresponding to any spectrum input can be determined by summing the wave packets or groups corresponding to each of the intervals $\Delta\omega$ in the spectrum. For distortionless transmission, the argument goes, one should expect that the envelope delay—the delay of all these packets—be constant. However, more careful consideration shows that the summation of these wave packets requires that the phase of the "carrier" within each group be known.[4] Since this phase depends upon the phase delay characteristic, it is clear that specifying only the amplitude and envelope delay from a few hundred kilocycles to four megacycles is insufficient to determine the transient response of the receiver. Furthermore, as (1) indicates, it is possible for the envelope delay of a receiver to be constant over this region even though the phase delay is varying, and hence constancy of envelope delay is a necessary but not a sufficient condition for distortionless transmission.

An example will clarify the significance of phase and envelope delay in the low-frequency region. If a signal carrying 200 kc square-wave modulation is applied to a receiver which has constant phase delay from 200 kc to 4.5 mc, then the output at the kinescope will be free of delay distortion. However, if this same signal is applied to a receiver which has constant *envelope delay* from 200 kc to 4.5 mc, then the output will in general be distorted. This distortion results from the asymmetric location of the picture carrier on the slope of the RF-IF band-pass filter. It is therefore invalid to extrapolate and assume that the envelope delay is constant from 200 kc down to dc—an assumption which would be valid for a conventional low-pass filter. In a television receiver, the envelope delay variations *below 200 kc* affect the spectrum delay *above 200 kc* and therefore have a profound effect upon the response to periodic wave forms having a fundamental frequency above 200 kc. This ties in with the fact previously noted that the transient response cannot be obtained by summing the "envelopes" corresponding to the "$\Delta\omega$ increments" without a knowledge of the "carrier" phase. An equally valid viewpoint is that a knowledge of the envelope delay above 200 kc, without specification of the phase intercept, is inadequate to enable determination of the transient response. For this reason, phase delay is a more useful tool than envelope delay in evaluating the transient response of television receivers.

Color Receiver Considerations

A critical examination of transient response is particularly timely, since the requirements of color receivers are more severe than those of monochrome.[5]

Fig. 4 shows the bandwidth occupied by the luminance and chrominance components. The I and Q color-difference signals are carried as in-phase and quadrature amplitude modulation of the 3.58 mc color subcarrier. The fact that the chrominance components occupy overlapping bandwidths imposes the requirement that the amplitude and delay be constant over this region in order to prevent cross talk between the I and Q signals. In addition, uniformity of delay is required to insure good coincidence of the luminance and chrominance contributions to abrupt transitions in color.

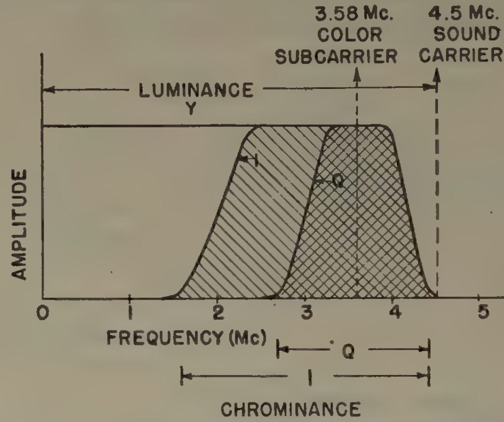


Fig. 4—Bandwidth of luminance and chrominance components of a compatible color television signal. Factors determining cross talk and relative delay are described.

The problem of insuring constant delay in the color sideband region is eased by the phase predistortion proposed in the NTSC signal specifications. This predistortion, shown in Fig. 5, is based on the high-frequency

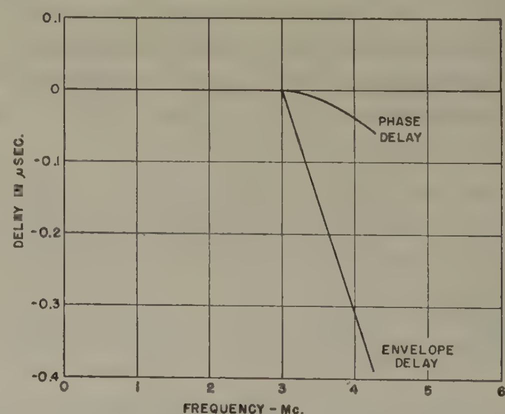


Fig. 5—The NTSC specification for the envelope delay at the transmitter and the equivalent phase delay.

phase distortion introduced by a "typical" receiver which has flat amplitude response to approximately 4 mc. This correction is given in terms of envelope delay and thus its interpretation requires some care. In particular, while an over-all constant envelope delay is

[4] R. V. L. Hartley, "Steady state delay as related to aperiodic signals," *Bell Sys. Tech., Jour.*, vol. 20, p. 223; 1941.

[5] G. H. Brown and D. G. Luck, "Principles of color television systems," *RCA Review*, vol. 14, p. 144; June, 1953.

sufficient to insure absence of cross talk, it is not sufficient to insure time coincidence of the luminance and chrominance unless, at low video frequencies, the envelope and phase delays are equal. In general, however, these delays are not equal in the low-frequency range because of the distortion resulting from vestigial sideband reception. For this reason, it is necessary to compare the *phase delay* of the luminance information with the *envelope delay* at the color subcarrier in order to obtain a measure of the coincidence of luminance and chrominance information.

In the absence of cross talk, the over-all color system may be viewed as one in which the color information is transmitted as separate amplitude modulation of in-phase and quadrature components of the color subcarrier. These modulations may then be considered as being synchronously detected at the receiver by a process equivalent to exalted carrier diode detection. This point of view indicates that the in-phase and quadrature signals are handled by the receiver in the same manner, and that there is only one equivalent response for both the in-phase and quadrature components. This response corresponds to low per cent amplitude modulation of the color subcarrier. The difference between the phase delay of this equivalent response and the corresponding phase delay of the luminance information is indicative of the degree of time coincidence of the chrominance and luminance.

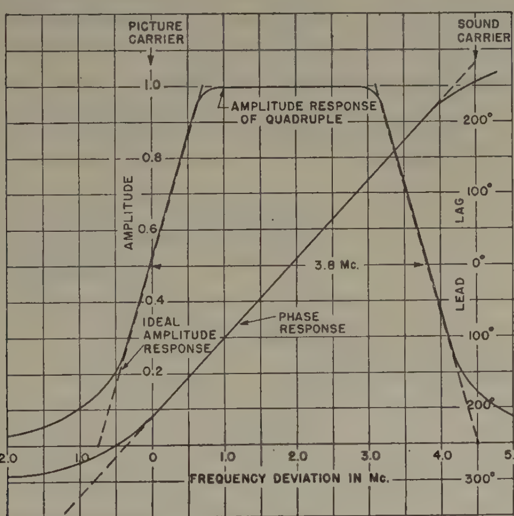


Fig. 6—The amplitude and phase characteristics of a flat-staggered quadruple having a 6 db bandwidth of 3.8 mc. The idealized amplitude characteristic of a receiver is shown dotted.

IF Amplifier Considerations

Phase distortion in the IF amplifier is a major factor in determining the electrical fidelity of the receiver. In general, however, the IF amplifier must be designed primarily to provide the required selectivity. When the selectivity requirements are met, the phase response is correspondingly determined since, in general, conventional IF circuits are minimum phase-shift networks. Despite the restrictions imposed by the need for adequate selectivity, typical IF designs currently in use show considerable variation in phase response.

To show what can be expected of IF amplifiers and the manner in which the phase characteristic is influenced by the amplitude characteristic, an investigation was made of the transient response of a flat-staggered quadruple. The bandwidth chosen was 3.8 mc to approximate the amplitude characteristics of an ideal receiver, as shown in Fig. 6.

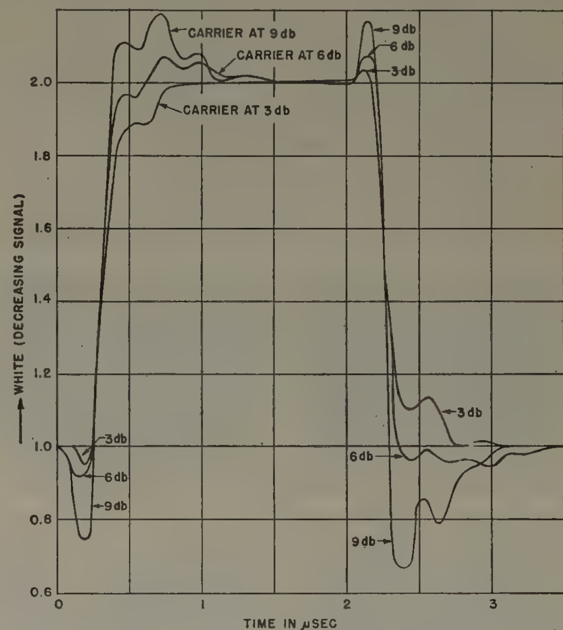


Fig. 7—The square wave response of a flat-staggered quadruple having a 3.8 mc 6 db bandwidth for low-per cent (2:1) modulation when the carrier is at 3 db, 6 db, and 9 db respectively.

Using the Laplace transform, the square-wave response of this IF amplifier was determined. (See Appendix I.) Fig. 7 shows the response for a 2-to-1 step change when the carrier is located at the 3 db, 6 db, and 9 db points of the attenuation characteristic. In each case the transition is preceded by a preshoot or precursory transient. The carrier at 6 db yields about the best performance. Lowering the picture carrier to the 9 db response point has the undesirable effect of increasing the preshoot and at the same time increasing the overshoot. Raising the carrier to the 3 db response point reduces the preshoot but has the disadvantage of increasing the rise time and introducing considerable smear.

The effect of increasing the per cent modulation is shown in Fig. 8. Here the transitions are shown with the carrier at the 6 db point for a 2-to-1 and for a 4-to-1 change in modulation level. If black level is taken as 72 per cent, then the 4-to-1 step would correspond to a variation from the 72 per cent carrier amplitude corresponding to black to the 18 per cent amplitude corresponding to (near) white. The effect of the increase in per cent modulation is to slightly increase the rise time and the amount of smear. At the same time the difference between the black-to-white and white-to-black transitions is increased. The noticeably larger preshoot in the case of the black-to-white transition is evident. This difference between the black-to-white and white-to-black transitions with increasing per cent modulation is characteristic of band-pass amplifiers in which the carrier is located off center.

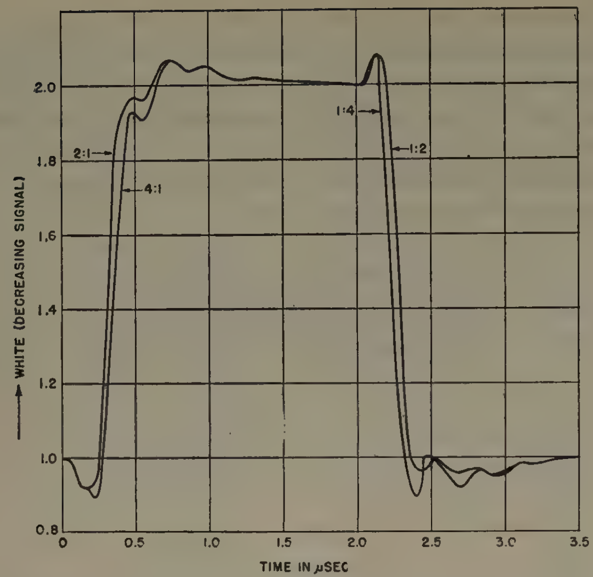


Fig. 8—Square wave response of a flat-staggered quadruple having a 3.8 mc 6 db bandwidth with the carrier at the 6 db point, for a modulation change of 2:1 and 4:1. The curves are normalized for comparison purposes.

The phase-delay curves for the quadruple of Fig. 6 are of interest and are shown in Fig. 9. The solid line shows the phase delay associated with double-sideband modulation of the picture carrier. The dotted line shows the phase delay associated with single sideband modulation of the picture carrier. Above 1.25 mc there is negligible difference between the two curves.

Since a quadruple 3.8 mc wide without traps has considerably less than normal IF selectivity, the effect of increasing the attenuation to 26 db at a frequency $\frac{3}{4}$ mc below the picture carrier was investigated. (See Appendix II.) The result as shown in Fig. 9b is greatly increased phase-delay distortion. If, in addition, the attenuation at the sound carrier is increased to 30 db, this added attenuation results in an increasing phase delay, which is characteristic of IF amplifiers, as the video modulating frequency approaches 4.5 mc.

The total phase delay distortion of the quadruple with the added attenuation below the picture carrier and at the sound carrier is shown in Fig. 9c. The resultant phase distortion is significant since the change in phase delay exceeds the 0.1-μsec value corresponding to the duration of a single picture element. All of these curves are based on the minimum phase characteristic corresponding to the assumed amplitude characteristic.

To evaluate the effect of mid-frequency phase distortion on the reproduction of a square wave, an approximate calculation was made of the effect of a phase delay distortion that varies linearly (a) from 0.05 μsec at zero frequency to 0 μsec at 1 mc, and (b) from 0.05 μsec at zero frequency to 0 μsec at 2 mc. As Fig. 10 shows, the effect of this distortion is to distort the step response of an "ideal" filter by increasing the amplitude of the preshoot and by introducing smear. Where the distortion extends as far as 2 mc, the amount of smear is approximately 20 per cent, i.e., the initial steep rise reaches only to the 80 per cent response point.

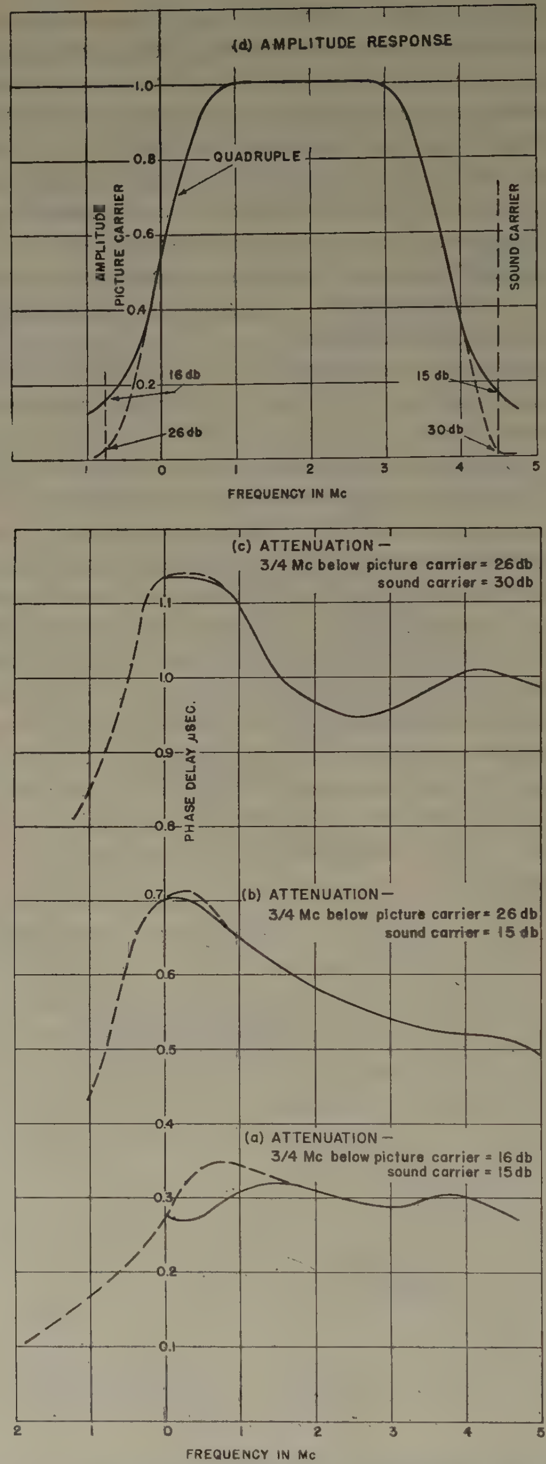


Fig. 9—Phase delay of (a) quadruple, (b) quadruple with added attenuation below picture carrier, and (c) quadruple with added attenuation below picture carrier and added attenuation at the sound carrier. The solid line represents the response to a double sideband signal, the dotted line to a single sideband signal. The amplitude response is shown in (d). Normally the total delay is less than in (b) and (c) because of the "after response" characteristic of conventional traps.

The preceding description points out the magnitude of the phase distortion that can be expected in video IF amplifiers and its effect in causing preshoot and smear. Investigation of the transient response of typical receivers has shown extremely wide variations in performance ranging from excessive smear and preshoot, to excessive overshoot and ringing. The delay character-

istics of these receivers show correspondingly large variations, particularly in the region from 0.1 mc to 3 mc. Correction of the delay distortion in this region has been found to be of far greater importance than correction of the distortion due to the high-frequency cutoff.

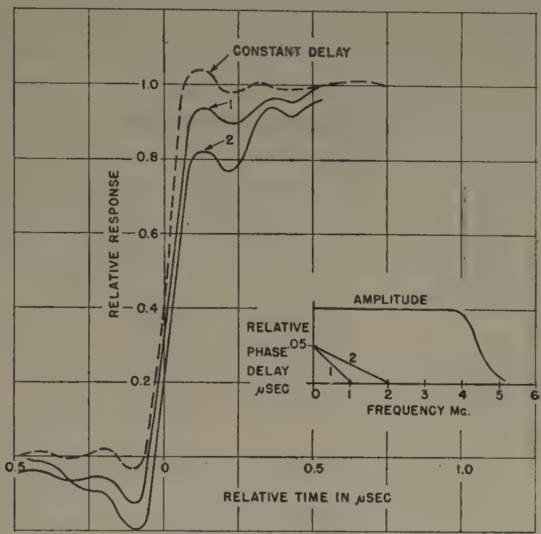


Fig. 10—The effect of mid-frequency delay distortion on the response of an idealized filter having a 4 per cent overshoot.

The distortion usually produced in the IF amplifier is considerably more severe than that produced by failure to correct the distortion produced by the vestigial sideband filter of the transmitter. This might be expected since the vestigial sideband filter attenuation does not "bite" as close to the carrier as does the IF amplifier characteristic.

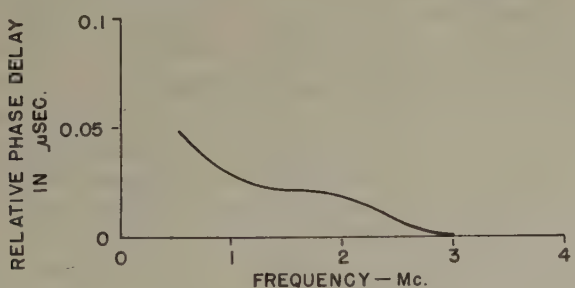


Fig. 11—The distortion introduced by a typical vestigial sideband filter at the transmitter.

A transmitter vestigial sideband filter typically introduces distortion having a peak value of 0.05 μsec and tapering off to zero at approximately 3 mc, as in Fig. 11. A typical receiver response, with and without correction at the transmitter for the vestigial sideband filter distortion, is shown in Fig. 12. Here again the effect of the distortion is excessive smear and preshoot.

The vestigial sideband distortion due to the transmitter is conventionally corrected in the transmitter by predistorting the modulating signal. The type of distortion required to provide this correction is shown in Fig. 12c. Note how the predistortion of the square wave is roughly "complementary" to that of the uncorrected distorted output.

IF amplifier distortion is usually corrected by the video peaking. Ideally, it would be desirable to eliminate phase distortion in the IF amplifier by using nonminimum phase-shift traps for the adjacent sound selectivity. However, in the present state of the art, the burden of providing the phase correction usually falls upon the video detector and video amplifier peaking circuits.

Lowering of the picture carrier to improve the overall transient response is occasionally used. This has the advantage of providing an overshoot which tends to compensate for the smear inherent in typical IF phase-delay distortion. However, it also tends to cause excessive preshoot and therefore is not a basic solution to the problem where maximum fidelity is desired.

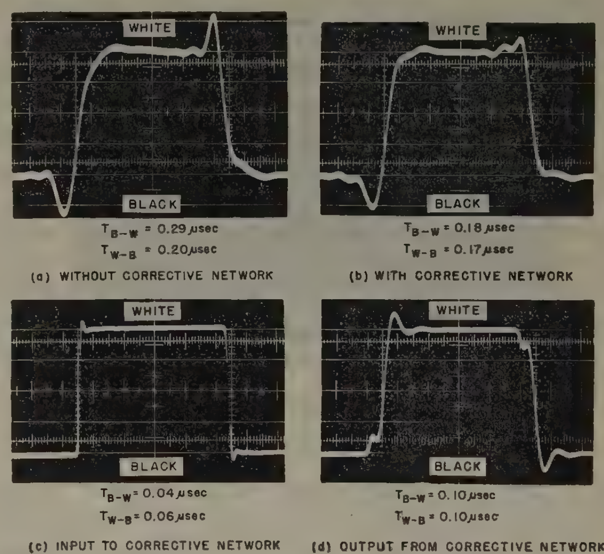


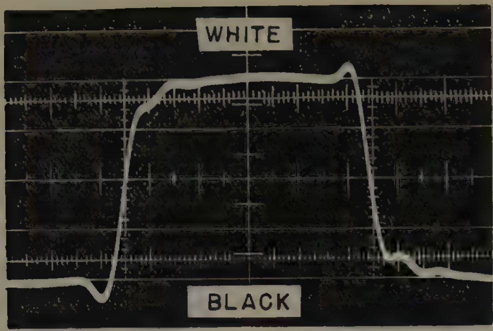
Fig. 12—A typical receiver response (a) with, and (b) without phase correction for the distortion introduced by the vestigial sideband filter at the transmitter. The response of the transmitter corrective network is shown at (d).

Video-Detector Peaking

Peaking of the video detector presents a problem because of the many factors which influence the results. These include the characteristics of the tuned circuits driving the detector, their resonant frequency with respect to the carrier frequency, and the ratio of unloaded to loaded Q. Because of this, it has been found desirable to consider the video detector as an integral part of the IF amplifier and to peak the video detector while observing the output corresponding to a modulated RF signal applied to the antenna terminals of the receiver.

Fig. 13a shows a typical square-wave response measured from the antenna terminals to the video detector with no added peaking; the output is taken across the video detector load resistance with only enough added capacitance to serve as an IF bypass. The improvement effected when the peaking is adjusted for optimum rise time and symmetry of transition is shown in Fig. 13b.

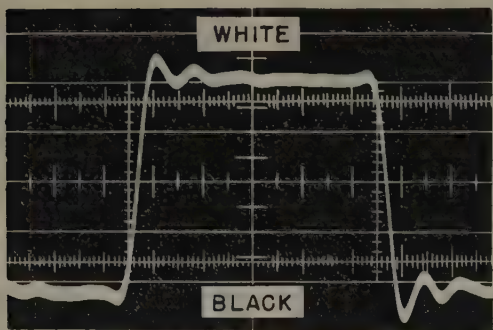
The frequently-used video detector generator impedance of 3,300 ohms (resistive) has been found to yield results of doubtful value. When the results of peaking the video detector by considering it an integral part of the



(a) WITHOUT PEAKING

$T_{B-W} = 0.28\,\mu sec$

$T_{W-B} = 0.22\,\mu sec$

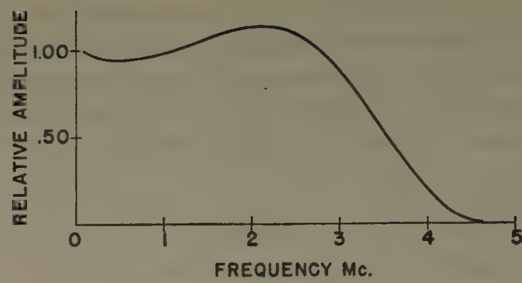


(b) WITH PEAKING

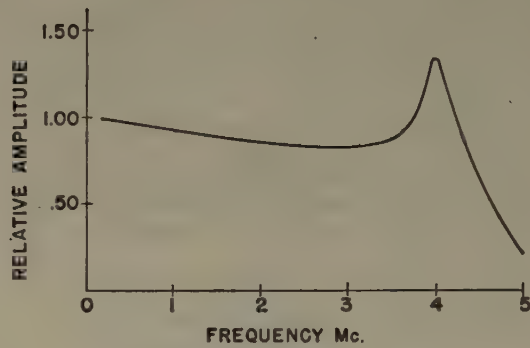
$T_{B-W} = 0.14\,\mu sec$

$T_{W-B} = 0.14\,\mu sec$

Fig. 13—The effect of detector peaking on the response of a typical receiver. (a) shows the response from the antenna to the detector with minimum shunt capacitance and no peaking; (b) shows the response with typical shunt capacitance and peaking adjusted for optimum.

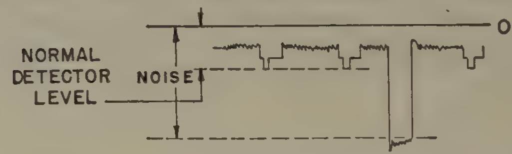


(a) USING VIDEO-MODULATED R-F SIGNAL

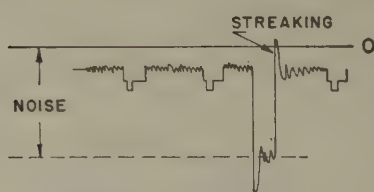


(b) USING VIDEO SIGNAL AND 3300 Ω DUMMY RESISTOR

Fig. 14—The effect of the video detector peaking can be determined by applying a modulated RF signal and measuring the output (a) at the video amplifier grid. Although this includes the IF amplitude response, it is a better index than the curve obtained by using a simulated 3,300 ohm dummy detector output impedance as in (b).



(a) NORMAL RECEIVER



(b) OVERPEAKED RECEIVER

Fig. 15—The effect of excessive ringing in the video detector peaking is to cause white streaking as shown at (b).

IF amplifier are compared with the results obtained by peaking conventionally with 3300 ohms, there is a wide disparity in the peaking. This is illustrated in Fig. 14 which shows (a) the amplitude response measured through the IF amplifier and video detector by using a video-modulated RF signal and (b) the amplitude response of the video detector as measured with a video signal and a 3,300-ohm dummy generator resistance. The difficulty of arriving at the optimum peaking by using the 3,300-ohm dummy resistor is apparent.

From the standpoint of obtaining maximum video signal output per milliampere of plate-supply current, it is desirable to use a relatively high video plate-load resistor in the video-output stage and to compensate for the resulting loss in high-frequency response by overpeaking in the video detector. If carried too far, this procedure results in white streaks following impulse noise. The mechanism is shown in Fig. 15. Even a relatively small percentage overshoot is effective in causing white level to be reached because of the absence of appreciable limiting up to the video detector. An equivalent amount of ringing in the video amplifier would not produce white noise because of the limiting in the video amplifier.

Video-Amplifier Peaking

In peaking the video amplifier of a television receiver, the normal data available for obtaining maximum gain-bandwidth product or maximum gain-rise time ratio is applicable only as a starting point. This is because the video amplifier must correct the phase delay distortion introduced by the video IF amplifier. When this distortion is corrected, the video amplifier amplitude response when viewed separately will appear far from optimum, although the over-all transient response is improved.

Experience has indicated that peaking of a narrow-band (3 mc) receiver is less difficult than peaking a wide-band receiver. This is the result of two factors: (1) the phase distortion produced in the IF amplifier is less and (2) the narrow band of the video amplifier makes it possible to phase correct the residual IF distortion without further compromising the over-all receiver bandwidth. The calculated phase-delay response of a 3 mc IF amplifier composed of two flat-staggered pairs is shown in Fig. 16. This may be compared with the considerably higher phase distortion of the wideband staggered quadruple, with comparable skirt selectivity, shown in Fig. 9c.

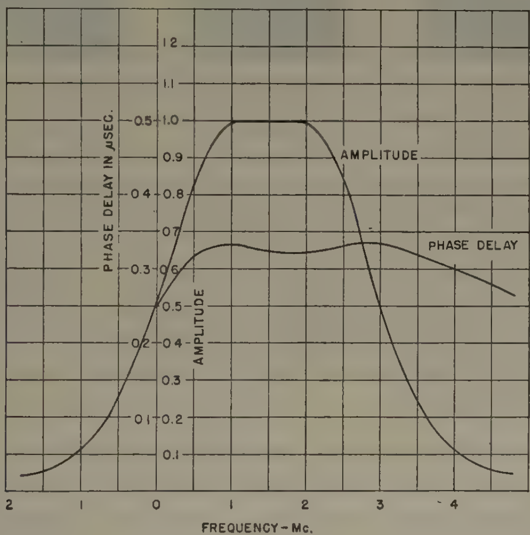


Fig. 16—Equivalent video phase delay of two staggered pairs having a 3.0 mc 6 db bandwidth.

Because of the need for correcting the IF phase delay distortion, the choice of load resistor, peaking component values, and the location of the termination (with respect to the low-capacitance side of the filter) are more critical than in an ordinary video amplifier where correction for IF phase distortion is not required.

The square-wave response alone is not an adequate index of video-amplifier peaking. It needs to be supplemented by examination of the swept amplitude response characteristic. Examination of both of these responses makes it possible to obtain the best square-wave response consistent with good high-frequency resolution, as indicated by the amplitude response.

Where only the square-wave response is used in determining the peaking constants, the tendency is for the amplitude response to be restricted at the high frequency end, and for the middle video frequency range to be boosted. This distortion of the amplitude response, when minimum phase-shift networks are used, makes possible correction of typical IF amplifier phase-delay distortion.

An effective method of improving over-all receiver transient response is the frequently used partially-bypassed cathode resistor. This introduces an overshoot in the square-wave response which is in the direction to compensate for IF phase distortion and to crispen the picture. Where the cathode resistor is variable, a control with one or two taps enables the amount of overshoot to be controlled as a function of the contrast setting.

A partially-bypassed video-amplifier screen has been successfully used in obtaining a similar result. This is particularly advantageous in stages which have a variable cathode resistor since the overshoot tends to be independent of gain. The partially bypassed screen circuit has also been effective in compensating for long black-to-white smear.

Optimum results in peaking video amplifiers are obtained when nonminimum phase-shift networks are used. Thus, the use of such all-pass networks, for example, the bridged-T network shown in Fig. 17, makes it possible to correct the phase-delay distortion without restricting the bandwidth. The improvement obtainable in the unit step response of a receiver by means of such a network is shown in Fig. 18. These networks have the general disadvantage that they must be operated at relatively low impedance level because the shunt capacitances in the video amplifier must be rendered negligible. Promising results, however, have been obtained with modified nonminimum phase-shift networks which provide good gain-bandwidth as well as the desired phase correction.

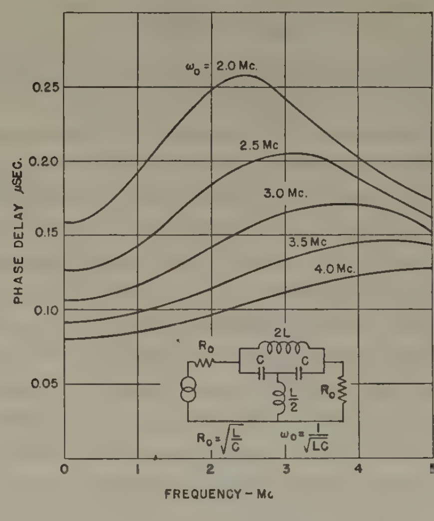


Fig. 17—Phase delay of an all-pass phase-correction network.

A source of poor transient response which not infrequently crops up is phase distortion in the 1-mc frequency range due to the disturbance caused by coupling the sync separator (and in some cases the AGC rectifier) to the video amplifier. As shown in Fig. 19, the distortion arises as a result of the variation in the impedance which the isolating resistor and the sync separator input capacitance shunts across the video peaking filter. The reaction on the filter is observed to be decreased by connecting the sync input to the kinescope feed point (A) rather than to the load resistor (B).

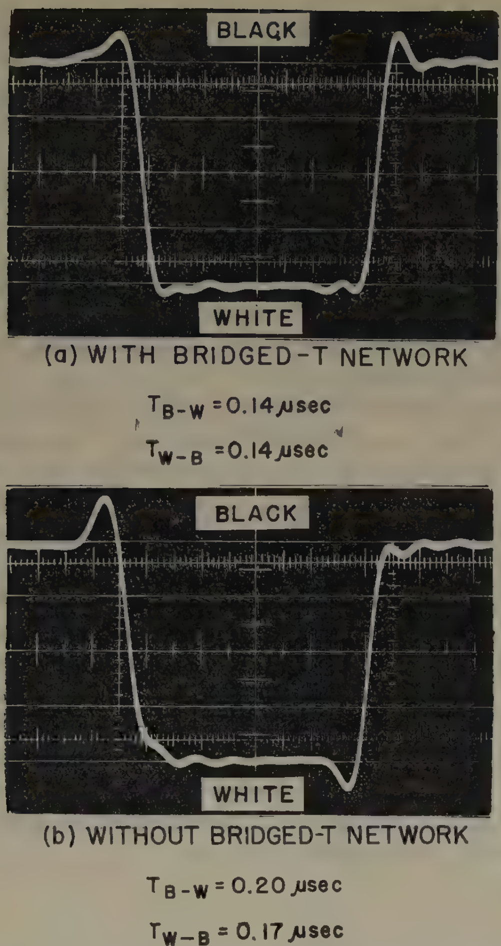


Fig. 18—Effect of compensating for the IF amplifier delay distortion by means of a bridged-T all-pass network in the video amplifier.

Where square-wave modulation of a carrier is employed without composite sync, it is essential that the sync separator not conduct during transition intervals and reflect an abnormally high capacitance across the circuit because of the Miller effect. Since the sync separator is normally cut off during the picture interval, it is necessary to artificially bias off the sync separator to avoid this excessive reflected capacitance.

Distortion due to sync-separator or sync-amplifier coupling can be eliminated completely by making use of the classic constant resistance circuit shown in Fig. 20a. A more general form of this circuit which enables an increase in the value of the resistance in series with the sync separater input capacitance is shown in Fig. 20b. For each circuit the input is purely resistive over the complete frequency range and is equal to $\sqrt{L/C}$. This pure resistance is then used in place of the single load resistor normally employed. These circuits give excellent results and are relatively noncritical of tolerances in components.

Measurement Techniques

A modulated signal generator, wide-band oscilloscope, and phase-delay measuring equipment are essential in obtaining optimum receiver transient response. A low-

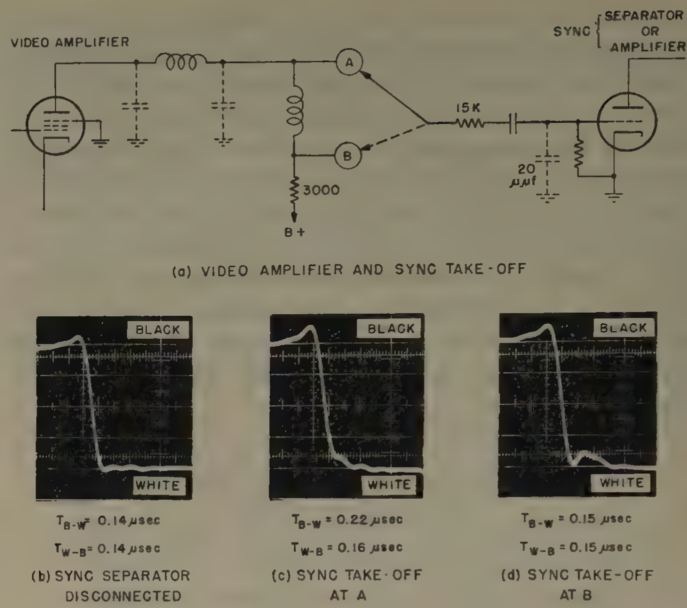


Fig. 19—The effect of coupling a sync separator (amplifier) to a video amplifier is shown. The smear is reduced when the sync input is connected to the junction of the peaking coils as shown in (c).

capacitance probe is helpful in making it possible to examine the transient response at any point in the receiver without adding more than 2 μμf.

Signal Generator

The signal source for measuring the high-frequency electrical fidelity of a television receiver ideally should be a miniature television transmitter including the vestigial sideband filter and the associated video compensation networks. Almost invariably, however, a

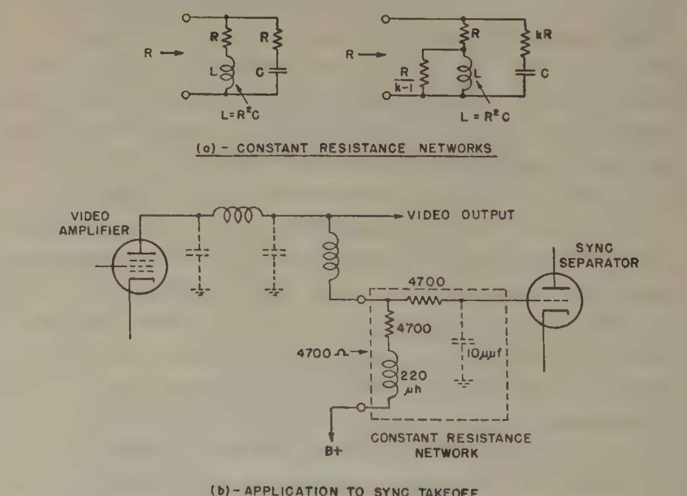


Fig. 20—The use of a constant-resistance network to eliminate smear caused by the sync separator being coupled to the video amplifier.

symmetrical double-sideband signal is used in testing television receivers. In addition to greatly simplifying the signal source, the use of a double-sideband generator simplifies monitoring of the signal since a diode video detector across the output terminals of the generator can be used.

The use of a double-sideband signal in receiver testing gives valid results under normal conditions where the receiver has negligible response to the sideband components which are normally absent in a vestigial sideband signal. Most IF ampliqers satisfy this requirement, as has been observed by the similarity of response to a double-sideband signal and to a properly-compensated vestigial-sideband signal. An exception to this general rule occurs when the receiver does not sufficiently attenuate the unwanted sideband, possibly because of a rise in response beyond the adjacent sound-carrier trap frequency. In spite of this, however, use of the double-sideband signal is indicated in all instances where a vestigial sideband signal of *known* characteristics is not available.

The response of a normal receiver to a vestigial-sideband signal will be the same as the response to a double-sideband signal provided that the transmitter is properly compensated for the phase distortion introduced by the vestigial sideband filter. Proper compensation in this sense consists of compensating the transmitter (modulator) so that the phase delay is constant over the transmission range. This can be done through the use of all-pass nonminimum phase-shift networks (for example, Fig. 17) in the video amplifier of the transmitter modulator, so that the phase can be controlled independently of the amplitude.

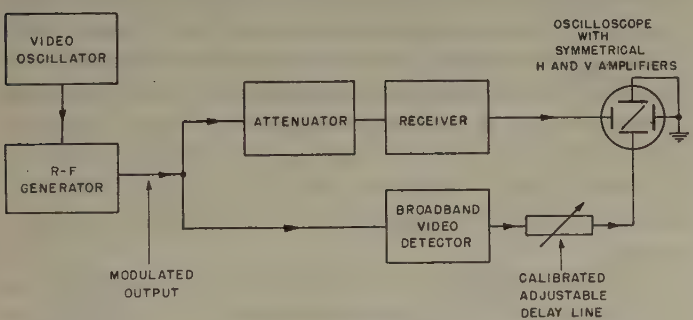


Fig. 21—A set-up for measuring the phase delay of a receiver. The calibrated delay line is adjusted to equalize the delays as indicated on the diagonal line.

Phase Delay

A set-up suitable for measuring phase delay is shown in Fig. 21. Here the delay through the receiver or video amplifier is matched against the delay of a calibrated continuously adjustable delay line. A scope with symmetrical horizontal and vertical amplifiers is used. This method is rapid and yields phase delay measurements accurate to 0.01 μsec. The data can be converted into envelope delay, for comparison with data specified in terms of envelope delay, by adding to each measured value a quantity equal to the angular frequency multiplied by the slope of the phase delay at that frequency. This is considerably more accurate than measuring the slope of the phase angle ϕ vs. frequency ω curve.

Standard Monitor

Variability in the quality of transmitted pictures has led to a tendency on the part of receiver designers to introduce more or less overshoot in the receiver. Widespread adoption of the standardization suggestions made by Kell and Fredendall seems desirable, particularly with respect to the need for a standard monitor.[6] In addition, more attention should be given to correcting at the transmitter for the distortion introduced by the vestigial sideband filter. Current FCC proof of performance includes no specification on the phase-delay characteristics of the transmitted signal.

Two approaches are possible in tying down the performance of the standard monitor. One is to consider the monitor as a black box and to specify its performance on a step-modulated standard double-sideband signal, i.e., its preshoot, its rise time, overshoot, etc. The other approach is to specify in detail the amplitude and phase response of the monitor. Neither one of these approaches by itself is entirely satisfactory. A combination of the two is desirable so that its performance on a double-sideband signal can be relied upon to provide an accurate indication of the adjustment of a vestigial sideband transmitter.

Appendix I

Step Response of a Flat-Staggered Quadruple

Calculation of the step response of the flat-staggered quadruple (Figs. 6, 7, 8) is based on the assumption of arithmetic symmetry. The location of the tuned circuits which comprise the quadruple may then be readily determined.[7] Using the Laplace transform and frequency-shifting the carrier down to dc then permits determination of the complex envelope response to a step up from zero carrier to full carrier.[8]

To determine the response to less than 100 per cent modulation, the initial value of the carrier must be added by complex addition to the complex envelope response. The absolute value of the result will then represent the actual envelope. To find the response corresponding to any arbitrary downward modulation, the complex envelope corresponding to 100 per cent modulation must be subtracted from the initial value of the carrier. The absolute value of this result then represents the actual envelope.

Appendix II

Effect of Added Adjacent Channel Selectivity on the Phase of a Quadruple

The effect of the added attenuation shown in Fig. 9b and 9c was calculated on the assumption of minimum-

[6] R. D. Kell and G. L. Fredendall, "Standardization of the transient response of television transmitters," *RCA Review*, vol. 10, p. 17; March, 1949.
[7] G. E. Valley and H. Wallman, "Vacuum Tube Amplifiers," McGraw-Hill Book Co., New York, N. Y., p. 176; 1948.
[8] M. Gardner and J. Barnes, "Transient in Linear Systems," John Wiley & Sons, New York, N. Y., p. 247; 1948.

phase shift.[9] The attenuation cut which provides additional adjacent channel sound attenuation starts at the picture carrier and extends below the carrier at a constant db per octave rate to form a low-pass filter which adds to the selectivity of the quadruple. Similarly, the attenuation cut on the co-channel sound side starts 3.8 mc from the picture carrier and continues at a constant db per octave rate to form a high-pass filter which again adds to the selectivity of the quadruple.

[9] T. Murakami, and M. Corrington, "Relations between amplitude and phase in electrical networks," *RCA Review*, vol. 9, p. 602; December, 1948.

Theory of Synchronous Demodulator as Used in NTSC Color Television Receiver*

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Summary—**It is shown that the plate output of the synchronous demodulators used in NTSC color television receivers will contain a variety of signals in addition to the desired color-difference signals. Among these are signals representing chromatic distortion due to rectification of the chrominance subcarrier, interference due to the passage of hf portions of the monochrome signal through the chrominance channel, and cross talk due to reaction between chrominance and hf monochrome signals. Estimates are made as to the seriousness of each undesired signal component, and it is concluded that there will be certain conditions under which each might produce a readily perceptible effect.**

Introduction

IN A COLOR TELEVISION SYSTEM it is necessary that three different types of color information be broadcast by the transmitter and interpreted by the receiver since color is essentially a three dimensional entity. The color co-ordinates employed in the NTSC color television system are luminance, dominant wavelength, and spectral purity, these being colorimetric quantities which serve as measures of the subjective sensations of brightness, hue, and saturation, respectively. The luminance information is conveyed in the NTSC system by a *monochrome signal*, which is transmitted as a 4.0-mc signal modulated onto the picture-carrier in exactly the same manner as is the ordinary video signal in monochrome television. The remaining two degrees of coloring information are transmitted by a *chrominance signal*, consisting of a subcarrier whose relative phase is determined by the dominant wavelength and whose amplitude is determined by the spectral purity of the color being transmitted. The chrominance subcarrier is situated 3.58 mc above the picture carrier. When the monochrome and chrominance signals are combined, the resulting signal is called the *color-picture signal*.

In a color receiver the chrominance signal is separated from the monochrome signal and translated into *color-difference signals*, which can be used in conjunction with the monochrome signal to control the color output of a tricolor picture tube. This translation of the chrominance signal into color-difference signals is performed by what are called "synchronous demodulators." These are basically similar to the mixer stages in superheterodyne radio receivers, the principal difference lying in the use of a locally-generated subcarrier of the same frequency as that of the incoming subcarrier. In addition, however, the synchronous demodulator in NTSC color television must detect both the amplitude and the phase of the subcarrier rather than just its amplitude alone. With this type of detection, both hue and saturation information can be deduced from the modulated subcarrier.

The present paper is concerned with an analysis of the action of a synchronous demodulator. The purpose of the analysis is to predict and describe any distortions in the reproduced color picture which arise as a result of the demodulation process. A short description of the synchronous demodulator will be given, and this will be followed by a mathematical analysis which will permit an evaluation of the relative importance of each interference or cross talk component occurring in the output.

The circuit for a typical synchronous demodulator such as might be employed in an NTSC color television receiver is shown in Fig. 1. The color-picture signal is passed through a 2.4–4.5-mc filter before reaching the modulator grid in order to remove the lf portions of the monochrome signal. If the subcarrier side-bands were transmitted in their entirety, the signal reaching the demodulator control grid could be expressed as[1]

* Decimal classification: R583.5. Original manuscript received by the Institute, February 10, 1953; revised manuscript received October 15, 1953.

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[1] It is to be understood in (1) and throughout the remainder of this discussion that the summation sign implies summation over n from $nh/2\pi = 2.4$ mc to $nh/2\pi = 4.5$ mc; these, of course, are the frequency limits imposed by the band-pass filter.

$$e_{g1} = A(t)\cos[\omega t - \alpha(t)] + \sum_n a_n \cos(nht + \phi_n), \quad (1)$$

in which the first term represents the subcarrier and its side-bands, the side-band distribution being determined both by the time-dependent amplitude $A(t)$ and by the relative phase $\alpha(t)$. Together, $A(t)$ and $\alpha(t)$ would convey the coloring information. The second term represents the hf portion of the monochrome signal, consisting of frequencies clustered around integral multiples of the horizontal line-scanning frequency h, as has been shown by Mertz and Gray.[2]

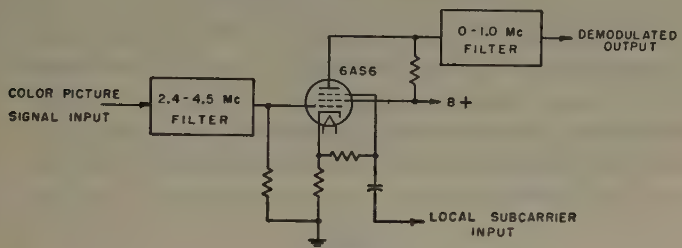

Fig. 1—Circuit of synchronous demodulator.

Although the upper sidebands of the subcarrier are suppressed at the transmitter in the manner shown in Fig. 2, so that the received chrominance signal is not entirely equivalent in form to a single wave of fixed frequency with varying amplitude and phase, nevertheless, in the interest of avoiding undue complication of the mathematics by effects not strictly attributable to the action of the demodulators alone, the effects introduced by vestigial side-band transmission of the subcarrier will be ignored in what follows.

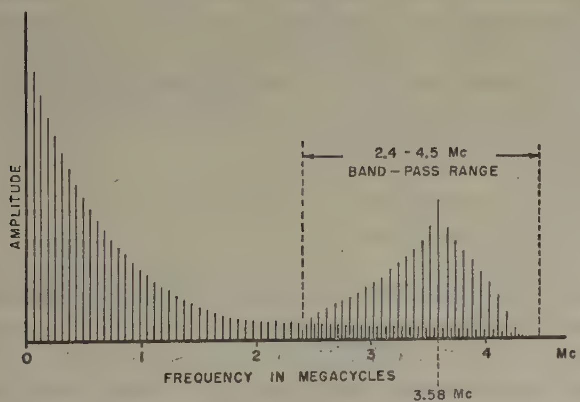

Fig. 2—The NTSC color-picture signal spectrum.

Demodulation is achieved by the introduction of a locally generated subcarrier which has fixed amplitude and relative phase and has the same frequency as the received subcarrier. This reference subcarrier is placed on the suppressor grid, whose signal voltage thus becomes

$$e_{g3} = B\cos\omega t. \quad (2)$$

[2] P. Mertz and F. Gray, "Theory of scanning and its relation to characteristics of transmitted signal in telephotography and television," *Bell Sys. Tech. Jour.*, vol. 13, pp. 464–515; 1934.

The plate output of the demodulator is passed through a 0–1.0-mc filter to reject frequencies higher than those contained in the desired color-difference signals. The mathematical analysis which follows will lead to the identification of the components of the plate current which contribute to the filter output.

Mathematical Analysis

The plate-current-signal-output of the tube in Fig. 1 is a function of both e_{g1} and e_{g3} and can be written symbolically as $i_p = i_p(e_{g1}, e_{g3})$ when voltages on cathode and screen are constant. It represents the increase in the plate current which results when signal voltages e_{g1} and e_{g3} are placed on control grid and suppressor, respectively, and is zero when e_{g1} and e_{g3} are zero.

If, now, one expands i_p as a double Taylor series in e_{g1} and e_{g3} and introduces the grid-to-plate transconductances for a pentode,

$$g_{m1} \equiv \frac{\partial i_p}{\partial e_{g1}} \quad (3a)$$

and

$$g_{m3} \equiv \frac{\partial i_p}{\partial e_{g3}}; \quad (3b)$$

there results the relation

$$\begin{aligned} i_p = {} & g_{m1}e_{g1} + g_{m3}e_{g3} \\ & + \frac{1}{2!}\left[\frac{\partial g_{m1}}{\partial e_{g1}} e_{g1}^2 + 2\frac{\partial g_{m1}}{\partial e_{g3}} e_{g1}e_{g3} + \frac{\partial g_{m3}}{\partial e_{g3}} e_{g3}^2\right] \\ & + \frac{1}{3!}\left[\frac{\partial^2 g_{m1}}{\partial e_{g1}^2} e_{g1}^3 + 3\frac{\partial^2 g_{m3}}{\partial e_{g1}^2} e_{g1}^2 e_{g3}\right. \\ & \left. + 3\frac{\partial^2 g_{m1}}{\partial e_{g3}^2} e_{g1}e_{g3}^2 + \frac{\partial^2 g_{m3}}{\partial e_{g3}^2} e_{g3}^3\right] + \cdots . \quad (4) \end{aligned}$$

The first term in (4) is that usually given for relating the plate current of a pentode to the signal on its control grid. Indeed, it is the only term which does not vanish when g_{m1} is essentially independent of e_{g1} and when e_{g3} is zero.

A tube frequently used in synchronous demodulators is the 6AS6 pentode. If it is operated with grid biases $E_{c1} = -2.0$ v and $E_{c3} = 0$, and if $|e_{g1}|$ and $|e_{g3}|$ never exceed 1 v and 5 v, respectively, then one can deduce from published characteristics the following values for the quantities occurring in (4):

$$g_{m1} = 3{,}200\ \mu\text{mhos}$$

$$\frac{\partial g_{m1}}{\partial e_{g1}} = 700\ \mu\text{mhos/v}$$

$$\frac{\partial g_{m1}}{\partial e_{g3}} = 350\ \mu\text{mhos/v}$$

$$\frac{\partial^2 g_{m1}}{\partial e_{g1}^2} = -600\ \mu\text{mhos/v}^2$$

$$g_{m3} = 430\ \mu\text{mhos}$$

$$\frac{\partial g_{m3}}{\partial e_{g1}} = 330\ \mu\text{mhos/v}$$

$$\frac{\partial g_{m3}}{\partial e_{g3}} = -475\ \mu\text{mhos/v}.$$

Since only currents at frequencies below 1.0 mc are of interest, only these need be used in (4). It follows immediately that the first two terms drop out, since neither e_{g1} nor e_{g3} contains lf components. The lf part of e_{g1}^2 can be found by squaring the right-hand side of (1) and rejecting every term representing a frequency above 1.0 mc. When this is done, it is found that

$$[e_{g1}^2]_{0-1} = \frac{A^2}{2} + A \sum_n{}' a_n \cos\left[(\omega - nh)t - \phi_n - \alpha\right] + \frac{1}{2}\sum_n a_n^2. \tag{5a}$$

The symbol $\sum'$ denotes summation from $nh/2\pi = 2.6$ mc to $nh/2\pi = 4.5$ mc and appears instead of $\sum$ since the quantity $\omega - nh$ exceeds 1.0 mc when $nh/2\pi < 2.6$ mc, as is easily verified. Similarly, it is readily found that

$$[e_{g3}^2]_{0-1} = \frac{B^2}{2} \tag{5b}$$

$$[e_{g1}e_{g3}]_{0-1} = \frac{AB}{2}\cos\alpha + \frac{B}{2}\sum_n{}' a_n \cos\left[(\omega - nh)t - \phi_n\right] \tag{5c}$$

$$[e_{g1}^3]_{0-1} = \frac{1}{4}\sum_m\sum_n a_m^2 a_n \cos\left[(2m - n)ht + 2\phi_m - \phi_n\right] \tag{5d}$$

$$[e_{g1}^2 e_{g3}]_{0-1} = 0 \tag{5e}$$

$$[e_{g1}e_{g3}^2]_{0-1} = 0 \tag{5f}$$

$$[e_{g3}]_{0-1} = 0. \tag{5g}$$

Using these values in (4) leads to

$$[i_p]_{0-1} = \frac{1}{2}\left\{700\left(\frac{A^2}{2} + \frac{1}{2}\sum_n a_n^2 + A\sum_n{}' a_n \cos\left[(\omega - nh)t - \phi_n - \alpha\right]\right) + 700\left(\frac{AB}{2}\cos\alpha + \frac{B}{2}\sum_n{}' a_n \cos\left[(\omega - nh)t - \phi_n\right]\right) - 475\left(\frac{B^2}{2}\right)\right\}$$
$$- 25\sum_m\sum_n a_m^2 a \cdot \cos\left[(2m - n)ht + 2\phi_m - \phi_n\right]. \tag{6}$$

Two terms in (6) can now be eliminated on practical grounds. Thus, the final cosine summation is negligible compared to that with coefficient $B/2$ since $25a_m^2 a_n \ll 175 a_n B$, the hf monochrome signal components being much lower in amplitude than B. A second simplification is brought about when one recognizes that a term which is constant in time is of no significance since it merely represents a fixed shift in the zero-signal plate current. Thus, the term in B^2 can be dropped. Equation (4) can thus be reduced to

$$[i_p]_{0-1} = 175AB\cos\alpha + 175A^2 + 175\sum_n a_n^2 + 175\left(\frac{A}{2} + B\right)\sum_n{}' a_n \cos\left[(\omega - nh)t - \phi_n\right]. \tag{7}$$

Interpretation of Results

The first term is proportional to the desired color-difference signal since it is proportional to $A\cos\alpha$, the chrominance subcarrier amplitude component in phase with the locally generated subcarrier. From (4) and (5c), it is seen that the desired signal arises because $\partial g_{m1}/\partial e_{g3} \neq 0$. The coefficient of $A\cos\alpha$ in the output is

$$\frac{B}{2}\,\frac{\partial g_{m1}}{\partial e_{g3}}.$$

The second term represents distortion of the chrominance signal due to the action of the tube as a nonlinear amplifier. Since this distortion is proportional to the square of the amplitude of the chrominance subcarrier, its effect will be most pronounced when A is large. Since the only time variation present is that of A itself, the effect in picture areas low in color detail will be to cause too strong a color signal to be delivered by each channel. If the system were designed so that the outputs of every chrominance demodulator in the system contributed with equal weight to the luminance output of the system, the net effect of this term would be to desaturate the color in the reproduced area by the addition of white. However, the NTSC color-picture signal is specified so as to be representable for color-difference signal frequencies below 500 kc by[3]

$$E_S = E_Y' + \frac{1}{1.14}\left[\frac{1}{1.78}E_{BD}\sin\omega t + E_{RD}\cos\omega t\right], \tag{8}$$

in which E_Y', E_{BD}, and E_{RD} are the monochrome signal, blue color-difference signal, and red color-difference signal, respectively. Actually, (8) is not applicable when color-difference components above 500 kc are involved, but present purposes do not justify the added complication which would arise upon treating with full rigor the true signal conditions at higher frequencies. It is now to be noted that E_{RD} is transmitted at nearly twice the level of E_{BD} as indicated by the presence of the factor 1.78 in front of the latter.

Now, in consequence of (8), the chrominance signal amplitude in (7) is related to E_{BD} and E_{RD} by

$$A = \frac{1}{1.14}\sqrt{\left(\frac{E_{BD}}{1.78}\right)^2 + E_{RD}^2}. \tag{9}$$

[3] "Petition of NTSC for Adoption of Transmission Standards for Color Television," Document NTSC-G-378, submitted to FCC on July 21, 1953.

Then

$$E_{RD} = 1.14A \cos \alpha_R \tag{10a}$$

and

$$E_{BD} = 1.14(1.78)A \cos \alpha_B, \tag{10b}$$

α_R and α_B being the phase displacements of the complete subcarrier from its two components proportional to E_{RD} and E_{BD}, respectively. Thus, the first term in (7) will be $175B/1.14$ times E_{RD} if the local subcarrier signal to the "red" demodulator is in phase with the red color-difference component of the incoming subcarrier. Or denoting "red" and "blue" demodulator outputs by $[i_p]_{0-1}{}^R$ and $[i_p]_{0-1}{}^B$, respectively, one obtains

$$E_{RD}{}^0 = \frac{1.14}{175B}\,[i_p]_{0-1}{}^R \tag{11a}$$

and

$$E_{BD}{}^0 = \frac{1.14(1.78)}{175B}\,[i_p]_{0-1}{}^B \tag{11b}$$

Finally, since the "green" color-difference signal E_{GD} is related to E_{RD} and E_{BD} by[4]

$$E_{GD} = -\frac{30}{59}E_{RD} - \frac{11}{59}E_{BD}, \tag{12}$$

it follows from (12) that attempting to recover E_{GD} in the receiver would lead to production of a signal $E_{GD}{}^0$ given by

$$E_{GD}{}^0 = E_{GD} - 1.14\frac{A^2}{B}\left[\frac{30}{59} + \frac{11}{59}(1.78)\right]. \tag{13}$$

Thus, (12) and (13) show that the weighting factors for the distortion in the color-difference channels due to the second term in (7) are 1, -0.84, and 1.78 for the red, green, and blue color-difference channels, respectively. It follows that the red drive signal to the picture display tube will be too large by an amount proportional to $1.14\ A^2/B$, that the green drive signal will be too *small* by 0.84 times this amount, and that the blue drive signal will be too large by 1.78 times this amount. Although the exact description of the color distortion caused by these effects is complicated by the presence of nonlinearity in the picture-tube transfer characteristic, it is evident that the distortion is in the nature of a displacement of the reproduced chromaticity from the desired one in the direction of a purplish blue.

In areas of minute color detail, the chrominance signal amplitude A may vary widely and cause considerable fluctuation in the magnitude of the above noted distortion toward blue. To minimize this effect, it is necessary that B exceed A by as large a factor as is practicable; for, aside from the factor $\cos\alpha$ in the first term, the desired signal and the chromatic distortion term amplitudes are in the ratio of B to A, as is evident in (7).

The last two terms in (7) are both of smaller magnitude than either of the first two, for the coefficients a_n are quite small in the neighborhood of the subcarrier, as is indicated in Fig. 2. It is also evident that the third term is to the fourth roughly as a_n is to B if $A \ll B$, so that the third term might, at first thought, be regarded as negligible in comparison with the fourth. This, however, is not necessarily true, for the frequency components of the fourth term are odd multiples of half the horizontal line-scanning frequency, so that the effect of each component on any one line tends to be cancelled when the eye averages over two fields of the picture. This is the meaning of "low-visibility" as applied to these frequencies. However, the third term in (7) is of high visibility, for no such cancelling effect occurs.

The third term represents distortion of the hf part of the monochrome signal due to the operation of the tube as a nonlinear amplifier. The effect will be most pronounced in areas high in luminance detail and will appear to the eye to be similar to the distortion toward blue which was discussed in connection with the second term. The present distortion, however, will occur in regions of large luminance variation regardless of saturation, whereas the former would occur in regions of high saturation regardless of luminance detail. The effect is readily observed when the RMA monochrome test chart is reproduced by the NTSC system. It appears as a purple tint in the 3–4-mc portion of the vertical-line resolution wedges.

The fourth term, because of its low visibility property, would not be expected to produce an appreciable visual effect if the brightness response of the picture tube were a linear function of the input signal. Most picture tubes are found to exhibit power-law responses with exponents between 2.0 and 2.4 over their principal ranges of operation, but experience seems to indicate that even this much departure from linearity is not sufficient to cause perceptible visual effect. It is nevertheless conceivable that the cross talk term in (7) might become visible under certain extreme conditions. Such a condition might be approached in areas high in luminance detail if a more nonlinear picture tube was used. In this case, the a_n's would be large because of the high luminance detail, and the brightness of the light on the screen would perform fairly large excursions above and below its mean level. Because of the exaggerated nonlinearity of the tube, the average brightness might then be appreciably higher than it would be if the cross talk were not present. Since this would generally occur in different degrees for different colors, a perceptible color distortion might result. High color saturation, by increasing A, would enhance this effect.

[4] D. C. Livingston, "Colorimetric analysis of the NTSC color television system," Proc. I.R.E., pp. 138–159, this issue.

The DC Quadricorrelator: A Two-Mode Synchronization System*

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Summary—**The dc quadricorrelator is a new form of automatic-phase-control circuit which, when applied to color synchronization, gives better performance and appears easier to manufacture than circuits previously used. It is intended to provide automatic color synchronization without need for a manually-operated frequency or phase control. The circuit combines good noise immunity with rapid pull-in, exceeding the capabilities of widely used earlier arrangements. Its performance and relative simplicity indicate a possible net reduction in over-all receiver cost. The DC Quadricorrelator also provides reliable, noise-immune, automatic switching of receiver circuits for monochrome or color operation.**

The dc quadricorrelator is a two-mode synchronization system in which the pull-in and hold-in modes of operation are made essentially independent of each other by means of a simple automatic switch. The basic principle, which is presented here in the environment of color synchronization, is also applicable to line and field synchronization for television.

Introduction

NTSC COLOR TELEVISION adds color to a monochrome picture by means of a narrow-band, frequency-interleaved carrier color signal which carries one component of the color information in its phase (the hue), and another component in its amplitude (the saturation). It is customary to provide a phase reference in the transmitted signal in order that receivers shall be able to measure the instantaneous phase angle of the carrier color signal so as to reproduce the desired color. This is accomplished by transmitting a short burst of oscillations at color subcarrier frequency during line retrace intervals, at a reference phase which corresponds to the $(Y-B)$ axis.

The color synchronization circuits in receivers have the purpose of deriving or generating a reference signal at the frequency and phase of the burst. This reference signal is used to demodulate the color video signal in the receiver.

Errors of the phase of the reference signal are visible as variations of hue of the reproduced picture. Dynamic as well as static variations can occur; dynamic errors result in fluctuating horizontal color streaks. Holding the peak static error to within 5 degrees, and the root-mean-square dynamic error due to thermal noise to 5 degrees for the noisiest acceptable pictures and correspondingly less for less noisy pictures, appears to be satisfactory.

The color synchronization circuits which thus far have been most widely used generate the reference signal in a local oscillator and compare it with the burst in a phase detector; the output of the phase detector is applied to a reactance tube which controls the oscillator frequency and hence phase. This arrangement is called an automatic-phase-control (APC) circuit.

In APC circuits both static and dynamic phase errors can be held within the selected limits by appropriate circuit design. However, in order for the APC circuit to perform its primary function of maintaining the oscillator phase, it must first pull the oscillator into frequency synchronism. A recent analysis[1] of such circuits has shown that when conventional APC arrangements are designed for good dynamic stability in synchronism, the ability of the circuits to pull into frequency synchronism is severely restricted. This restriction may be expressed in terms of the time T_F required for the oscillator to pull into frequency synchronism, the frequency interval Δf over which the oscillator is pulled, and a convenient measure of the ability of the circuit to suppress phase fluctuations. These fluctuations occur when the burst signal is accompanied by noise. Since the APC loop acts to restrict the rate at which phase fluctuations of the reference oscillator can occur, the measure commonly used is the equivalent noise bandwidth f_{NN} associated with the APC loop. In accordance with the usual definition, the equivalent noise bandwidth is the extent of pass-band with unity transmission which transmits the same noise power. The value of the noise bandwidth f_{NN} required to hold rms phase variations to acceptable values is about 100 cycles; this permits color sync noise to be masked by video noise, over a wide range of signal levels.

The conventional APC loop exchanges pull-in time for stability at an expensive rate. The frequency pull-in time T_F varies as the square of the frequency interval Δf and inversely as the cube of the noise bandwidth f_{NN} in accordance with the following relation:

$$T_F > 4 \frac{(\Delta f)^2}{f_{NN}^3}. \qquad (1)^2$$

For example, the time required to pull the oscillator for 2.5 kilocycles will not be less than 25 seconds if the noise bandwidth is 100 cps.

The signal itself permits very much better performance, with the time required for pull-in approaching the

* Decimal classification: R583.13: Original manuscript received by the Institute, October 2, 1953.

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[1] D. Richman, "Color carrier reference phase synchronization accuracy in NTSC color television," NTSC Technical Monograph No. 7, PROC. I.R.E., pp. 106–133, this issue.

[2] Many equations in this paper are derived in the companion paper listed in reference 1. The numbers of the corresponding equations are given herein for those who would be interested in the derivations. This equation was (3).

value

$$\frac{5}{f_{NN}} \qquad (2)^{3}$$

for signal-to-noise ratios of interest and for values of Δf up to half the burst repetition frequency of 15734+ cps. For the same example, the required stabilization time is 0.05 second.

Knowing such substantial improvement to be available, an investigation was made of receiver synchronizing systems which overcome the limitations imposed by (1); this led to appreciation of the attractiveness of the dc form of quadricorrelator.[4]

The dc quadricorrelator achieves a substantial part of the available improvement. In particular, it permits an independent choice of stability and of pull-in time.

The principle of operation of the dc quadricorrelator is that it supplements the APC loop with an additional detector operating in quadrature with the phase detector of the APC loop. This detector develops an auxiliary dc control voltage only when the system is in synchronism. The presence or absence of this dc voltage distinguishes between the in-sync and not-in-sync modes of operation. This voltage acts as a control signal which switches a circuit parameter so that the APC loop has the necessary properties for good pull-in when it is not in synchronism and the necessary properties for good dynamic stability when it is in synchronism. This two-mode action permits the noise bandwidth to be made narrow enough to eliminate horizontal streaking of highly colored areas on noisy signals without affecting the pull-in performance. These circuits are intended to eliminate the need for a customer-operated color synchronization control by having a range of rapid pull-in which is in excess of the anticipated frequency drift during normal tube life. The dc gain in the phase control feedback loop is made high enough to hold static phase errors to a selected small limit.

A further use to which the dc control voltage can be put is to turn the color circuits on and off. Since it is desirable that color receivers operate on monochrome transmissions, and since spurious beatnote patterns of high visibility can be produced by high-frequency video components when the color-carrier reference oscillator is nonsynchronous, some form of switch should be provided to turn off the chrominance channel during reception of monochrome transmissions. Customer convenience militates against a manual switch. Some types of "color killers" using peak detectors tend to be unreliable under noisy conditions. However, the dc quadricorrelator develops a control voltage which reliably indicates, even at low values of signal-to-noise ratio, whether the system is (a) in synchronism, or (b) either out of synchronism or operating from a monochrome signal which has no burst.

This automatic chrominance switch also results in the elimination of the usual colored stripes during pull-in; a monochrome picture appears instead. This means that during extreme conditions of operation, when pull-in may require a few seconds (such as near the end of tube life), an acceptable picture is always provided.

Fig. 1 presents two pull-in time curves which show the improvement obtained with one form of dc quadricorrelator. The curves show pull-in time as a function of the frequency interval over which the oscillator is pulled. The narrow curve in the center represents the earlier APC loop. The wide curve shows measured performance for a quadricorrelator having the same "in-sync" performance including the same value of noise bandwidth.

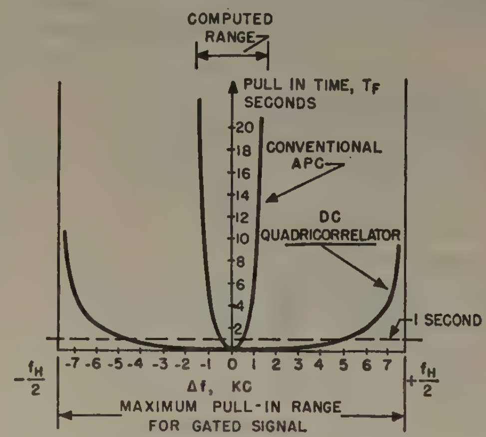


Fig. 1—Illustrative measured pull-in time curves.

Properties of the APC Loop Applicable to the DC Quadricorrelator

As an aid to understanding the principles of the dc quadricorrelator, it appears useful to summarize the physical characteristics of the APC loop. The form of APC loop of interest is solid line portion of Fig. 2a.

The APC loop consists of a local reference oscillator, a phase detector (the synchronous ϕ detector) which responds to the phase difference between the synchronizing signal S and a reference signal R_Q from the oscillator, a filter network having a specific form of passband, and a reactance tube which controls the oscillator frequency and phase.

When the APC loop is in synchronism and the signal-to-noise ratio is high, it acts as a linear feedback system; the signals S and R_Q applied to the phase detector normally differ by 90 degrees; any deviation from this relationship produces an appropriately positive or negative increment of voltage which shifts the oscillator frequency; since the reference signal R_Q is fed back from the oscillator to the phase detector, the phase difference between R_Q and S tends to be held at a constant value.

[3] *Op. cit.*, eq. (9).

[4] The term quadricorrelator is derived from the words QUADRature Information CORRELATOR and has been applied to synchronization systems which make use of the correlation existing between a pair of measurements of a synchronizing signal made in phase quadrature. Another form has been presented in NTSC Technical Monograph No. 7 (reference 1) to help establish the high level of performance permitted by the color burst.

During pull-in, however, the phase goes through its entire range of values many times. The phase detector then provides a differential voltage having alternately positive and negative polarity. This acts to slow or speed up the rate of change of phase difference between S and R_Q on consecutive half cycles of this differential voltage and by virtue of the loop feedback modifies the average frequency difference[5] so that pull-in may occur under certain conditions. An analytical solution to this nonlinear problem has recently been obtained and is included in NTSC Technical Monograph No. 7.[6]

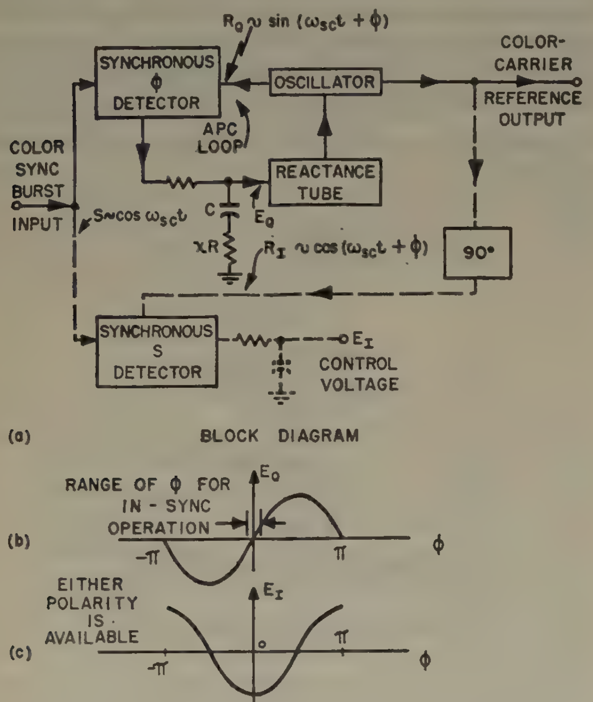


Fig. 2—Derivation of switching control voltage in dc quadricorrelator.

Properties of the APC loop may be expressed in terms of four basic measurable parameters from which its performance characteristics can be computed. These are used in the few formulas presented below to derive numerical results useful in design.

Measurable Parameters

(1) The reactance tube sensitivity β is the rate of change of oscillator frequency, f, with reactance tube grid voltage, E.

$$\beta = \frac{\partial f}{\partial E} \text{ cycles per volt.} \tag{3}$$

(2) The phase detector static characteristic output voltage E_Q is the product of the sine of the angle ϕ by which the phase difference between the sync signal S and reference signal R_Q differs from 90 degrees, with a gain constant, μ.

$$E = \mu \sin \phi. \tag{4}$$

This is indicated by Fig. 2b. At the operating point $\phi=0$,

$$\mu = \left|\frac{\partial E}{\partial \phi}\right|_{\phi=0} \text{ volts per radian.} \tag{5}$$

(3) The transmission characteristic of the filter has the value of unity for dc and the essentially constant value m for frequencies higher than approximately half the noise bandwidth of the APC loop. Normally $m \ll 1$. Its value is determined by noting the amplitude of beat-note developed at the filter ouput when the reactance tube is inoperative. This amplitude is $m\mu$. The filter includes the series output impedance of the phase detector.

(4) The fourth measurable parameter is the time constant of the shunt elements of the APC filter, which is xRC.

$$xT \equiv xRC. \tag{6}$$

It is convenient to use the following two derived parameters:

$$f_c = |\mu \cdot \beta| \quad \text{the DC loop gain in cps;}$$

and (7)

$$mf_c = |m\mu \cdot \beta|, \quad \text{the AC loop gain in cps.}$$

It is a characteristic of the APC loop that these loop gains have the dimensions of frequency, as a result of the dimensions for μ and β stated above, and since "radians" is a dimensionless quantity.

Performance Characteristics

(1) The static phase error of the loop is the phase shift $\Delta\phi$ required to generate enough control voltage to shift the oscillator frequency by the required amount, Δf. As shown below, $\Delta\phi$ varies directly as Δf and inversely as f_c.

$$\sin \Delta\phi = -\frac{\Delta f}{f_c}. \tag{8}$$[7]

For example, if it is desired that the static phase error $\Delta\phi$ not exceed 5 degrees, while the maximum anticipated oscillator frequency drift, due to all causes, is 2.5 kc, the minimum acceptable value of dc loop gain f_c may be computed from (8) to be 27.7 kc. The value $f_c=30$ kc has been used in experimental receivers.

(2) When the input signal to the APC loop includes noise, the instantaneous phase of the input signal varies with noise fluctuations. This is detected by the phase detector and results in phase modulation of the oscillator. The APC loop reduces the effectiveness of the noise by responding primarily to slow variations; it re-

[5] K. R. Wendt and G. L. Fredendall, "Automatic frequency and phase control of synchronization in television receivers," Proc. I.R.E., vol. 31, pp. 7–15, Jan. 1943.
[6] Richman, ibid.

[7] *Op. cit.* eq. (C-2).

stricts the bandwidth of the phase modulation symmetrically about the burst frequency. The dynamic in-sync properties of the loop are described by the shape of the effective APC loop passband and by the equivalent rectangular noise bandwidth, f_{NN}, of the APC loop. Fig. 3 shows representative shapes of passband with a damping coefficient K as a parameter. By definition,

$$K \approx \frac{\pi}{2}(mf_c \cdot xRC). \qquad (9)^{8}$$

The ordinate $|Q(f)|$ represents the ratio of phase variation of the reference oscillator to effective phase variation of the color synchronizing burst at any modulation frequency f; the modulation frequency f defines the rate of phase modulation.

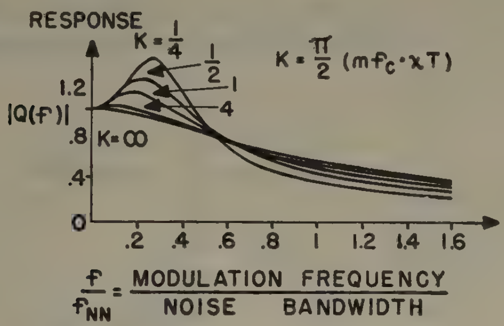


Fig. 3—APC loop modulation response.

Values of K greater than about 1/4 appear to be acceptable for in-sync operation. It has been found that a clear optimum value for K exists with regard to pull-in.[9,10] This occurs for values between 1/2 and 1 for the APC loop alone.

A noise bandwidth f_{NN} near 100 cps appears optimum, both theoretically and experimentally. The noise bandwidth can be computed from the following equation:

$$f_{NN} \approx \frac{\pi}{2}\left(mf_c + \frac{1}{2\pi xRC}\right) = \frac{\pi}{2} mf_c\left(\frac{K + 1/4}{K}\right). \qquad (10)^{11}$$

By assigning values of f_{NN} and K in (9) and (10), the appropriate values of mf_c and xRC can be determined.

(3) At this point f_{NN}, K, and the maximum intended values of Δf and $\Delta\phi$ have been assigned numerical values. The values chosen for these four quantities uniquely determine the constants of the APC loop with the exception that f_c has been defined only with regard to its minimum value.

Still to be determined are the useful pull-in range, and the pull-in time T_F. The maximum range over which pull-in can occur (even though it may take infinite time) is expressed by the formula,

$$\Delta f_{\max} = f_c\sqrt{2m - m^2} \approx \sqrt{2f_c \cdot mf_c}\left(\leqq \frac{f_H}{2}\right). \qquad (11)^{12}$$

This holds up to near $f_H/2$ (half line frequency) the maximum range permitted by the gated nature of the signal. Thus, by making the dc loop gain f_c very large, the maximum pull-in range can be made to approach $\pm f_H/2$. This is not, however, really satisfactory, since pull-in times are excessive in this extra range. *The real requirement on pull-in is that for some selected reasonable value of pull-in time T_F the corresponding pull-in range Δf_T should be as large as possible.* The equation for Δf_T is

$$\Delta f_T \approx \frac{mf_c}{\sqrt{\frac{xRC}{T_F} + \frac{m}{2}}} < mf_c\sqrt{\frac{T_F}{xRC}}\left(\leqq \frac{f_H}{2}\right). \qquad (12)^{13}$$

The limiting form of (12) in which f_c is made indefinitely large while xRC, T_F, and mf_c are held constant is obtained by use of the fact that $(m/2) = (mf_c/2f_c)$.

The simple APC loop cannot exceed the pull-in performance indicated by the following equation, in which T_F has been expressed in terms of f_{NN} and K [derived from (12), (10), and (9)] and optimized for K. The optimum value of K is found by differentiation to be $K = \frac{1}{2}$.

$$T_F = \left(\frac{\pi}{2K}\Delta f\right)^2\left(\frac{K + 1/4}{f_{NN}}\right)^3 > 4\,\frac{(\Delta f)^2}{f_{NN}^{\,3}} \qquad (13a)^{14}$$

or

$$\Delta f_T < \tfrac{1}{2}(T_F)^{1/2}(f_{NN})^{3/2}\left(\leqq \frac{f_H}{2}\right). \qquad (13b)$$

For example, if a maximum pull-in time T_F of one second is desired with a noise bandwidth f_{NN} of 100 cps, then (13b) shows that the maximum frequency drift of the oscillator should not exceed 500 cps. If the frequency drift were the previously assumed value of 2.5 kc, then the pull-in time with this circuit could not be less than 25 seconds, which is believed excessive.

Use of the auxiliary-dc control voltage, which indicates whether or not the system is in synchronism and automatically modifies the design parameters to favor the required mode, effectively doubles the number of design choices and overcomes this limitation.

Derivation of the Auxiliary DC Control Voltage

The components which are added to the APC loop to derive the auxiliary-dc control voltage are shown by broken lines in Fig. 2a.

A reference signal R_I, which is shifted in phase by 90 degrees with respect to the reference signal R_Q, is

[8] *Op. cit.* eq. (C-12).
[9] *Op. cit.*
[10] D. Richman, "APC color sync for NTSC color television," Convention Record of the I.R.E., part 4, 1953. (See Fig. 8.)
[11] Richman, "Color carrier reference phase synchronization accuracy in NTSC color television," *ibid.*, eq. (C-21).
[12] *Op. cit.* eq. (D-25).
[13] *Op. cit.* based on eq. preceding (C-17).
[14] *Op. cit.* eq. (3), (C-22).

supplied to the synchronous S detector. These two synchronous detectors have been designated the ϕ and S detectors because the output of one varies linearly with ϕ, while the other output varies linearly with S at the nominal operating point in synchronism. The output of the S detector is averaged in the low pass filter, and is represented by the symbol E_I. Fig. 2c shows the variation of E_I with ϕ; this is shown as a negative cosine wave.

The outputs E_I and E_Q are effectively in quadrature; this means that when E_Q is zero, which is the nominal operating point, E_I is at a peak value. When the system is in sychronism, the actual value of ϕ is held by the APC loop to within the narrow range indicated. This means that when the system is in synchronism, the voltage E_I is maintained at maximum amplitude; either polarity is obtainable.

When the burst is present, but the system is not in synchronism, or when no burst is present, the dc or average value of E_I will be zero. Thermal noise will not produce a dc output as long as the S detector performs as a true synchronous detector. This is discussed quantitatively later. Application of E_I for switching circuit parameters to improve pull-in is discussed next.

Methods of Switching for Improved Pull-In

The two methods of switching to obtain improved pull-in which are presented in this paper are called the variable gain and variable ratio types. In the variable gain type the dc and ac gains are both increased to improve pull-in, while in variable ratio type ratio of ac-to-dc gain is appropriately increased for this purpose.

Fig. 4a shows a simplified circuit diagram for a portion of the variable gain type of dc quadricorrelator, showing the switching method. Here the loop gains are increased by increasing the value of μ when the system is not in synchronism. If the increase is by the ratio M, (12) shows that the pull-in range Δf_T for some selected pull-in time T_F also increases in the ratio M (except as limited by the gated nature of the signal to $\pm f_H/2$). In this case, the ac loop gain mf_c increases by the ratio M, while the other parameters in the equation, xRC, T_F and m remain constant. Since m is a constant, the dc and ac loop gains change in the same ratio.

The pull-in time improvement ratio is complicated to express numerically as it is a variable, becoming infinite in the added range where the more elementary circuit cannot pull in at all. The comparison is perhaps best shown by curves such as Fig. 1.

Fig. 4b shows a simplified circuit diagram for a portion of the variable ratio type, showing the switching method. Here the ac beatnote voltage, fed to the reactance tube when the system is not in synchronism, is made larger by increasing the ac transmission through the APC filter for that condition. If this increase changes m to $M'm$, (12) shows the increase in pull-in range for finite pull-in time to be between $\sqrt{M'}$ and M', except where the range is limited to $\pm f_H/2$.

Some designs of the dc quadricorrelator will have a *nominal range* of rapid pull-in, Δf_T, which gives results in excess of half line frequency if computed from (12) (which is, however, adequate for normal designs of conventional loops). It is useful therefore in quadricorrelator design to have an equation which is consistent with the limitations imposed by the gated nature of the signal. A useful approximate (first order) correction of (12) which does this is:

$$\Delta f_T \approx \frac{mf_c}{\sqrt{\frac{xRC}{T_F} + \frac{m}{2} + \left(\frac{mf_c}{f_H/2}\right)^2}}. \tag{14}$$

Both methods of switching can be applied simultaneously.

The in-sync performance, such as the thermal noise immunity, is not affected by the addition of enhanced out-of-sync gain.

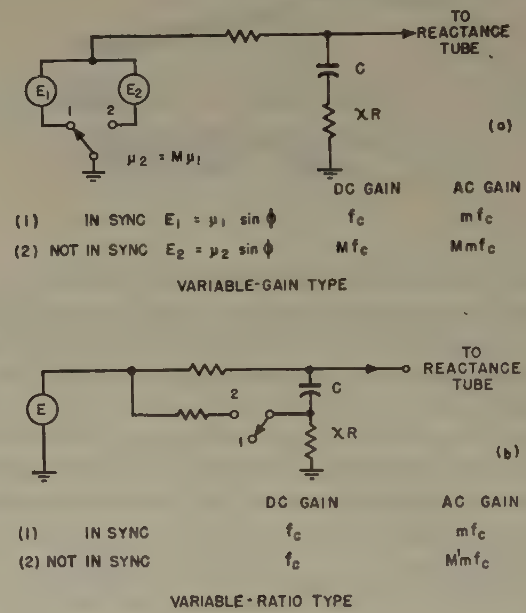


Fig. 4—Approximate equivalent circuits for simple forms of dc quadricorrelator.

Complete Block Diagram for a DC Quadricorrelator

A block diagram for a complete color synchronizing system is shown in Fig. 5; part of the chrominance channel is also included.

At the input, the color synchronizing burst is amplified and keyed by line flyback in the keyed synchronizing amplifier. It is then applied to a pair of synchronous detectors operating in quadrature; the ϕ detector is part of the APC loop, while the S detector determines the operating mode. The ϕ detector output is fed through the APC filter to the reactance tube and oscillator. The oscillator output is amplified in the buffer amplifier, which drives the quadrature transformer.

The quadrature transformer provides a pair of signals, which differ in phase by 90 degrees, to the color demodulators; one of these signals is fed back to provide the reference signal R_Q for the ϕ detector while the other provides the reference signal R_I for the S detector. The S detector output is filtered in the low-pass filter.

The resulting dc control voltage at the output of the low-pass filter is fed to a color killer (dc amplifier) which provides either zero or a large negative bias to activate or disable the chrominance amplifier.

The variable-gain type of dc quadricorrelator is obtained by using a common filter for the plate return of the chrominance amplifier and the screen circuits of the keyed sync amplifier and the buffer amplifier as shown by connection A. The APC loop gain is high when the screen voltages are high; this occurs when the current drawn by the chrominance amplifier is small, that is, when the system is not in synchronism.

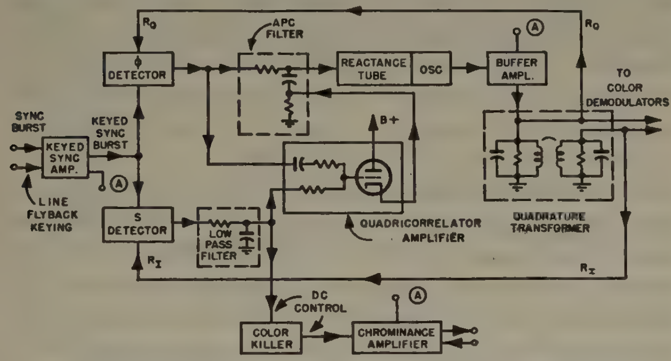


Fig. 5—One form of dc quadricorrelator sync system and receiver connections.

The variable-ratio type is obtained by the use of a triode amplifier connected as shown; a small fraction of the ϕ detector output is ac-coupled to the grid of the triode which is biased on or off by the dc control voltage from the S detector. When conducting, the triode increases the ac transmission to the reactance tube.

This block diagram shows how both the variable-gain and variable-ratio methods of improving the pull-in performance may be used simultaneously. The pull-in curve shown in Fig. 1 was obtained with a circuit based on the block diagram of Fig. 5.

Reliability

A two-mode sync system should desirably be able to determine which mode is appropriate at all values of signal-to-noise ratio which provide acceptable video content; if it cannot, it will sometimes operate in the wrong mode. The dc quadricorrelator has the ability to determine the desired mode because the ranges of switching voltage corresponding to the in-sync and not-in-sync modes do not overlap, even under severe thermal noise interference, when it is properly designed. This ability to get into and remain in the proper mode may be explained with the aid of the curves shown in Fig. 6 which describe these ranges.

Explanation of Fig. 6

The curves relate the output voltage from the low-pass filter following the S detector to the filter noise bandwidth. This noise bandwidth is different from and not related to the noise bandwidth f_{NN} of the APC loop. The output level 1 represents the nominal detector in-sync output with nominal burst amplitude when noise is absent, and 0 represents the output for the not-in-sync mode without noise.

The output from the synchronous detector will fluctuate in the presence of noise. The effective extreme values of the fluctuation range have been computed from a knowledge of the signal-to-noise ratio S_0/N_W, the noise bandwidth of the low-pass filter, the duty cycle of the sync burst, and an assumed keying interval of twice the burst duration.

(The signal-to-noise ratio S_0/N_W is the ratio of line and field sync-pulse amplitude (25 per cent of carrier amplitude) to rms noise amplitude (25 per cent of effective peak noise amplitude for the full video bandwidth). The nominal peak-to-peak burst amplitude is also S_0.)

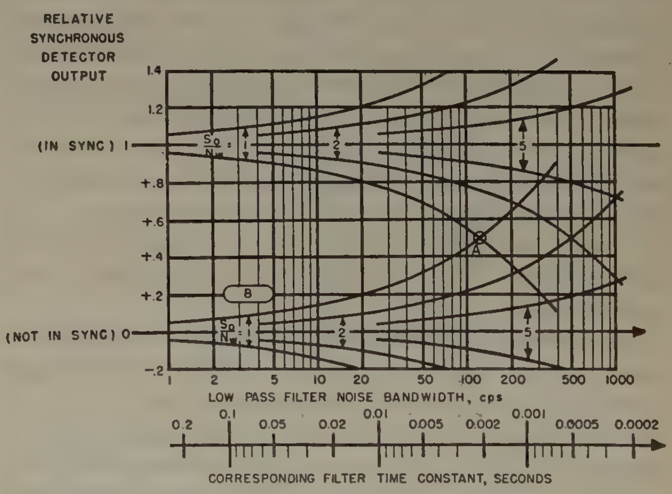


Fig. 6—Theoretical reliability of synchronous detectors.

The curves of Fig. 6 which flare out from the asymptotic values 1 and 0 as the noise bandwidth increases show extreme values of the fluctuation ranges for values of S_0/N_W equal to 1, 2, and 5. The curves show that if the noise bandwidth of the low-pass filter following the S detector is made small enough, there are intermediate ranges of detector output which will *not* occur in the normal operation in either mode. If, therefore, a transition or switching point is located within this region, the system can be designed to get into and remain in the proper mode even though much noise is present. For example, if proper operation is desired down to $S_0/N_W=1$, the curves show that the switching amplitude should be near 0.5, while the noise bandwidth should be 137 cps (point A) or less, for completely certain distinction between the two modes, under ideal conditions of operation.

Deviations in Asymptotic Values from Ideal

The high level of performance just described can be achieved as long as the asymptotic or average values of detector output for in-sync and not-in-sync operation are actually 1 and 0, respectively.

The zero asymptote can be maintained reliably in this circuit and will be considered first. There are three (nonsynchronous) conditions when it may apply: (a) when the burst but no noise is present; (b) when noise but no burst is present, and (c) when both are present.

With regard to item (a), there are two facts about APC loops (presented in reference 1)[15] which are relevant. The first of these is that during the pull-in interval, the rate of change of the average frequency difference is very slow compared to the average frequency difference; beatnote wave forms have essentially the same shape from cycle to cycle. The second is that the beatnote wave form from the ϕ detector has even symmetry. Since the S detector output differs in phase by 90 degrees from the ϕ detector output, it has odd symmetry and hence no dc component.

With regard to item (b), it is useful to use the following property of linear synchronous detectors (discussed in the Appendix). The average output due to the presence of a signal and random noise (thermal noise is a good example) does not depend on the amount of noise present. As long as the two synchronous detectors are linear and in phase quadrature, in the absence of a burst noise will tend to produce outputs from both detectors having an average value of zero.

If burst and noise are present simultaneously, the beatnote wave forms fluctuate but still give an average value of zero.

Synchronous detectors may fall short of the ideal with regard to the unity asymptote. This occurs because when the burst is present and the system is in synchronism, the nominal output of the S detector varies as $\cos \phi$, as shown by Fig. 2c. Thus when ϕ fluctuates due to the presence of noise in the input to the APC loop, the output from the S detector will fluctuate. Since $\cos \phi$ has its extreme value when $\phi = 0$, this being -1 in Fig. 2c, all deviations in the value of $\cos \phi$ due to the fluctuations are in the same direction. The simple first order approximation to the magnitude of the average S detector output for in-sync operation may then be expressed in terms of the root-mean-square phase fluctuation ϕ_{rms} by the following relationship:

$$1 - 1/2(\phi_{rms})^2 \approx \cos \phi_{rms} \qquad (15)^{16}$$

where ϕ_{rms} is in radians.

[15] *Op. cit.* (See Fig. 22c, and Appendix D.)

[16] The relation is derived as follows: If the phase fluctuations are such that the relative number of times the phase falls in the incremental range $d\phi_1$ between ϕ_1 and $\phi_1 + d\phi_1$ is $p(\phi_1)d\phi_1$, then the average S detector output is proportional to

$$\frac{1}{2\pi}\int_{-\pi}^{\pi} p(\phi_1) \cos \phi_1 d\phi_1 = 1 - (1/2)\overline{\phi^2} + (1/24)\overline{\phi^4} + \cdots .$$

By definition $\overline{\phi^2} \equiv (\phi_{rms})^2$.

Consequences of the Deviations

The actual value of ϕ_{rms} depends on the signal-to-noise ratio and the value of APC loop noise bandwidth, f_{NN}, being proportional to the square root of f_{NN}. Since the DC Quadricorrelator is a two-mode system, there are two values of f_{NN} which must be considered; these are (a) the value of f_{NN} when the system is synchronous and has switched its parameters for normal in-sync operation, and (b) the value of f_{NN} immediately after pull-in to frequency synchronism has been achieved but before the switching has taken place. For normal in-sync operation with usable values of ϕ_{rms}, the term represented by (14) is close enough to unity so as not to be a limitation. Proper operation can be obtained as long as the value of this term exceeds the switching level.

The ability of the system to narrow its APC loop noise bandwidth f_{NN}, immediately after pulling into frequency synchronism depends on the value of the noise bandwidth and on the signal-to-noise ratio (and hence ϕ_{rms}) in the not-in-sync mode. Of those circuits which achieve a specific pull-in time, the one with the narrowest not-in-sync value of noise bandwidth and thus the smallest rms phase fluctuation, ϕ_{rms}, generates the strongest dc control voltage for achieving the desired mode. It, therefore, has the greatest potential of pull-in performance under noisy conditions. In this regard the variable-gain type of dc quadricorrelator appears superior to the variable-ratio type, while the most efficient form appears to be another arrangement in which the optimum value of K for pull-in, stated earlier following (9), is achieved. All of these arrangements appear capable of exceeding the levels of performance required for synchronization with the color burst at values of signal-to-noise ratio which may provide usable video signals.

Other Threshold Effects

The variations in asymptotic values just described are inherent to the form of the system. Operation of APC loops at low values of signal-to-noise ratio sometimes involves other "threshold" effects which should be considered in determining the system design parameters.

In particular, some specific forms of detectors fail to perform as true synchronous detectors at very low signal-to-noise ratios. The common form of balanced double-diode "phase" detector has this limitation, although it appears to be capable of proper operation at signal-to-noise ratios greater than about 1/2 and has been used in dc quadricorrelator instrumentations; this threshold level of signal-to-noise ratio appears to be low enough to be satisfactory. When used as the S detector of a dc quadricorrelator it has been designed to operate in or near region B of Fig. 6. Lowering the switching level from the ideal value of 0.5 also allows for variations of receiver gain.

The additional abscissa scale has been provided in Fig. 6 to indicate numerical values of the switching time constant associated with the low-pass filter noise

bandwidth. Time constants of the order of 0.05 to 0.1 second correspond to designs in region B.

When the balanced double diode detector is used as a ϕ detector, it includes within it an alternative voltage which has been considered for use in controlling a color killer. This operates by envelope detection of the burst in one part of the ϕ detector. This control voltage becomes unreliable, for fundamental reasons discussed in the Appendix, at high enough signal-to-noise ratios to be the limiting factor in determining the service range for receivers using it. The limitation results from inability to maintain the zero asymptote.

Factors Determining Pull-In Range Requirements

At this point all of the basic properties have been presented for a sync system which permits an effectively independent choice of the pull-in range for a selected pull-in time. It is therefore appropriate to consider next the factors which determine how large the pull-in range needs to be.

Oscillator and Reactance-Tube Stability

The range of rapid pull-in should exceed the total anticipated frequency drift caused by variations of both the oscillator and reactance tubes. A reasonable value of frequency stability for a well designed and constructed lc oscillator at 3.58 mc is believed to be ± 500 cps. Crystal oscillators have additional limitations when used in APC loops, and are beyond the scope of the present paper. However, in either case the oscillator must be controlled in frequency and phase by a reactance tube. The variations in frequency caused by changes in the characteristics of the reactance tube under typical conditions are roughly comparable with the variations due to the oscillator. For example, oscillator frequency variations caused by some designs of reactance tube may be held within ± 1 kc over a reasonable life period. Thus a nominal range of ± 2.5 kc for some selected pull-in time would be adequate on these assumptions if there were not the other limiting factors discussed below in this section. The experimental circuit discussed later achieves an actual range of ± 5 kc for one second of pull-in time.

A representative desirable reactance-tube sensitivity curve is shown in Fig. 7a. The nominal operating point is at the origin. The peak frequency shift from cutoff to the nominal operating point caused by the reactance tube should be just enough that the curve is substantially linear over the operating range, thereby providing full gain over this range. The peak variation in frequency due to undesired reactance-tube variations is the product of the nominal peak frequency shift and the peak per cent variation of the transconductance of the reactance tube. In addition to keeping the peak frequency shift small, it is also desirable to degenerate variations in reactance tube performance. Fig. 7b shows a typical reactance tube with dc degeneration. Here a bypassed cathode resistor acts to reduce variations in average current and transconductance.

For stability, the reactance-tube sensitivity β should be small. For example, a value of 3 kc/volt, with a peak frequency shift between 10 and 15 kc is believed to represent good practice. It holds the possible effects of contact-potential variations and heater hum to levels at which no apparent difficulties have been encountered in these aspects. The desirable value of 30 kc for the dc loop gain f_c is then obtained by making the phase detector sensitivity μ equal to 10.

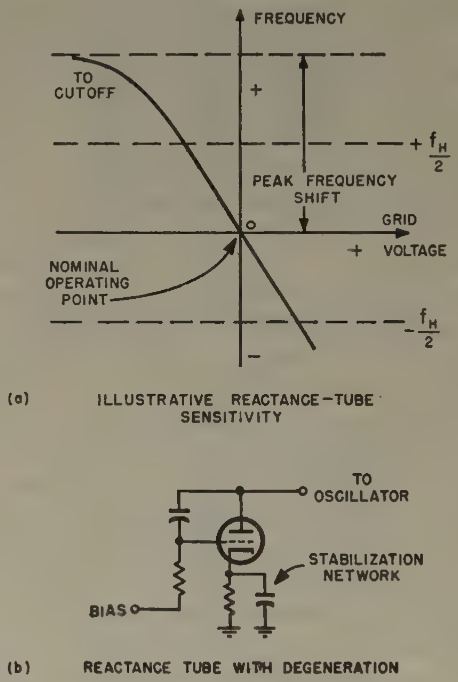


Fig. 7—Factors relating to reactance-tube stability.

Unbalance

Unbalance is a term used to describe the effective shift in phase detector output voltage in some circuits when the burst is switched on. It occurs, for example, as a result of lack of symmetry of balanced phase detectors or of spurious coupling from the oscillator into the synchronizing channel.

Unbalance normally has the effect of shifting the limits of pull-in range, without changing the total range, or the point of minimum pull-in time. This is illustrated in Fig. 8a where curve 1 is shifted to curve 2 by unbalance effects.

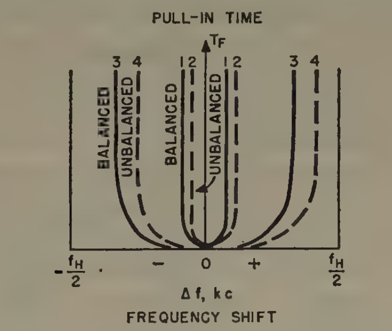
This effect, which is characteristic of APC loops, effectively reduces the pull-in range because it varies from receiver to receiver, and only the minimum range can be depended on.

If the pull-in range is increased by the variable gain method, curves 3 and 4 result. Obviously, excess pull-in performance provides a means of overcoming unbalance.

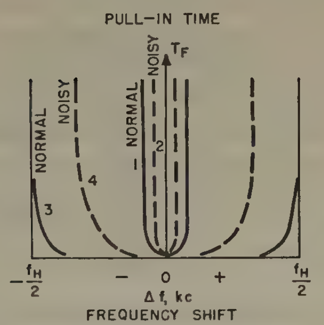
The variable-ratio type and the composite type, in which both the gain and ratio vary, also overcome unbalance effectively.

Decoding Efficiency

The operations performed upon the synchronizing signal with regard to deriving from it the desired information may be broadly separated into decoding and integration, that is, obtaining the information from the signal and then taking its average. Decoding primarily occurs in the synchronous, or phase, detector. The most efficient decoding is the one which requires the shortest period of integration[17] to average the signal to a specified measure of accuracy.



EFFECT OF UNBALANCE ON PULL-IN CURVES



EFFECT OF REDUCED DECODING EFFICIENCY ON PULL-IN CURVES

Fig. 8—Limitations overcome by excess pull-in performance of the dc quadricorrelator.

Signal information may be lost in several ways; for example, with identical signal inputs, several of the forms of phase or synchronous detectors which could be used in APC loops may have different output signal-to-noise ratios. In some circuits, the signal output may fall when noise is present, due to undesired rectification effects. This can cause a reduction in the pull-in range of an APC loop and an increase in its average pull-in time. Receiver gain variations can cause a similar limitation.

This reduction of pull-in range for the unsupplemented APC loop is illustrated in Fig. 8b by curves 1 and 2. Curves 3 and 4 show how "excess" pull-in performance obtained with the dc quadricorrelator is used to minimize the effect of these degradations of APC loop performance.

[17] *Op. cit.* See "System efficiency and the distribution of timing information" for a discussion of other factors relating to decoding efficiency.

It is of particular interest that for those designs of the dc quadricorrelator which have so much pull-in performance that the range is primarily limited by the gated nature of the signal, the above limitations cause relatively little degradation of performance. Thus, the effects of unbalance, poor decoding efficiency, or inadequate receiver gain, may be "swamped out" or suppressed. For example, the circuit measured for Fig. 1 has a nominal pull-in range [based on (12)] of ± 12 kc; it is limited to ± 5 kc by the gated nature of the signal. When the effects discussed above occur, the pull-in is still limited primarily by the gated nature of the signal, and the range is therefore not reduced substantially.

Application of the Theory to Experimental Circuits

Color synchronizing circuits following the block diagram of Fig. 5 have been investigated experimentally and tested in developmental receivers. The circuits were based on the following system parameters which have been discussed earlier in this paper:

For in-sync operation, $f_c = 30$ kc, $f_{NN} = 125$ cps, $K = 1/3$, $\beta = 3$ kc/volt, $\mu = 10$ volts/radian, and the low-pass filter time constant was equal to 0.08 seconds. The circuit combines the variable-gain type with a switching ratio of 3/1 and a variable-ratio type with a switching ratio of 10/1.

The circuit used a pentode (1/2 6U8) as the keyed sync amplifier. Balanced (6AL5) double-diode circuits were used for both ϕ and S detectors. A double triode (12AT7) was used as reactance-tube and oscillator. Another pentode (1/2 6U8) was used as the buffer amplifier. The quadricorrelator amplifier was a sharp cutoff triode (1/2 12AX7).

The associated color killer was a dc amplifier triode (1/2 6U8) plate pulsed from line flyback so as to provide zero or a negative bias in its plate return for turning the chrominance amplifier on or off.

Experimental Curves

Measured curves of pull-in time as a function of the frequency interval over which the oscillator is pulled are shown in Fig. 9 for four possible circuit designs derivable from Fig. 5, namely, the conventional APC, the variable-gain, variable-ratio and the composite types of dc quadricorrelator.

(1) The APC loop with no added features was obtained by removing the quadricorrelator amplifier triode and short circuiting the ouput of the color killer to ground. In this condition the circuit exhibited the in-sync performance common to all four arrangements. The noise bandwidth was 125 cycles; the relation of pull-in time to frequency shift is given by the narrow curve in the center of the chart. The measured pull-in range for one second of pull-in time was ± 550 cycles. The broken-line curve represents the theoretical limit of

performance for a conventional APC circuit with the same noise bandwidth; the limit is obtained by increasing the dc loop gain f_c toward infinity. This can provide about ±700 cycles of range for one second of pull-in time.

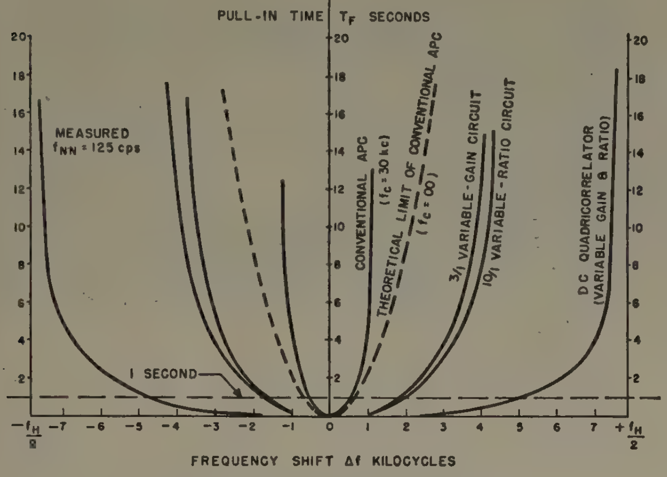


Fig. 9—Experimental pull-in curves.

(2) The variable-gain type of dc quadricorrelator was obtained by removing the short circuit from the output of the color killer, which then permitted the loop gain to be automatically switched by a ratio of about 3/1 between high gain and low gain conditions. This increased the range for a pull-in time of one second to about ±1,650 cycles.

(3) The variable-ratio type was obtained by reinserting the triode quadricorrelator amplifier, shifting the plate return of the chrominance amplifier to a separate B supply filter and readjusting the screens of the two switched pentode amplifiers for the proper voltage for in-sync operation. The color killer remained operative. The measured pull-in range of this circuit for one second of pull-in time was about ±1,900 cycles for a switching ratio of about 10/1.

(4) Pull-in performance of the complete circuit based on Fig. 5 is given by the outermost curve of Fig. 9 in which a pull-in time of one second is achieved with a pull-in range of about ±5,000 cps. These curves do not represent the limiting improvement obtainable; rather, the circuit tested was designed for a specific level of performance.

In over-all experimental tests this circuit has appeared to perform satisfactorily in receivers at all values of signal-to-noise ratio for which the video content was usable.

Conclusions

The new form of color synchronizing circuit described in this paper is designed to give automatic color synchronization without the need for a customer operated frequency or phase control, combining good noise immunity with rapid pull-in. It includes a new reliable form of color killer for monochrome reception. The dc quadricorrelator appears to provide a practical solution to the problem of obtaining a high-quality color synchronizing system at reasonable cost.

Appendix

Properties of Detectors

Several forms of detectors are used in color synchronizing systems. These may be used, for example, as ϕ detectors or as S detectors. These detectors differ in the manner in which they respond to noise; at low signal-to-noise ratios some detectors fail to operate properly, as a result of some nonlinear effects which can occur in these detectors at very low values of signal-to-noise ratio.

Linear synchronous detectors do not have these limitations; signal information is not destroyed in the detection process; in fact, a pair of linear synchronous detectors in quadrature can decode all of the available information in the signal regardless of the noise level.

Some basic mechanisms by which nonlinear detectors can cause nonessential limitations can be illustrated by comparing an envelope detector with a linear synchronous detector under conditions of threshold performance. Performance at threshold levels, where the noise equals or exceeds the signal, is of particular importance in burst synchronization. Normally, television receivers operate down to values of signal-to-noise ratio at which threshold effects begin to appear in line and field synchronization. However, the burst is transmitted as a single-sideband subcarrier signal of small amplitude; the pulse signal-to-noise ratio at the output of an ideal synchronous detector which demodulates the burst is 12 db poorer than the pulse signal-to-noise ratio for line or field synchronizing signals, and therefore, if service range is not to be impaired, burst synchronization circuits must operate properly under threshold conditions.

Probability Distribution of Amplitude Coefficients

One means of describing signals is by the probability distribution of amplitude coefficients, that is, the relative probability that any particular amplitude will exist during any arbitrary time interval. These probabilities are known for the following cases where random noise has been added to sine waves of various relative amplitudes: (a) the distribution of envelope amplitudes for a sine wave plus noise,[18] which related to the output of an ideal peak detector; and (b) the distribution of amplitudes along one axis, which relates to the output of an ideal synchronous detector. See Fig. 10a and 10b.

The curves show that the distribution of noise output amplitudes for an envelope detector is a function of signal-to-noise ratio, while for a synchronous detector it is unaffected by the signal-to-noise ratio. In particular,

[18] S. O. Rice, "Mathematical analysis of random noise," *Bell System Tech. Jour.*, vol. 23, pp. 282–332; July 1944, and vol. 24, pp. 46–156; Jan., 1945.

the average output of a synchronous detector goes to zero when the signal is removed, while the envelope detector gives an average output which is a function of the noise level; this occurs because the envelope amplitude is always a positive quantity. The average output from the synchronous detector depends only on the signal; the noise causes fluctuations of the output about the average.

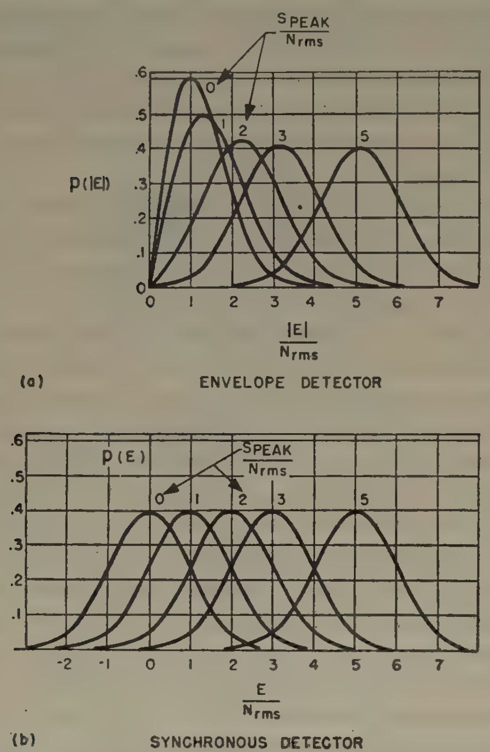


Fig. 10—Comparison of envelope and synchronous detector.

Fluctuations of Synchronous Detector Output Due to Noise

The fluctuations of the output from a synchronous detector in the presence of noisy signals are easily described in terms of the noise bandwidth of the low-pass filter following the synchronous detector. This has been shown in Fig. 6.

The range of variation of this output is plotted from the following equation:

$$\frac{\text{Peak Noise}}{\text{Peak Burst}} = \frac{16N_W}{S_0}\sqrt{\frac{f_A}{df_W}}, \tag{15}$$

where $(1/2)S_0$ is the nominal burst amplitude, $N_W/\sqrt{f_W}$ is the noise density, f_A is the noise bandwidth of the low-pass filter and d is the duty cycle of the burst. The total video bandwidth is f_W. The equation is derived from the product of the following four factors: (1) the ratio of the effective peak value to the rms value of noise is 4; (2) the ratio of rms noise to peak burst is $N_W/(S_0/2)$; (3) the effective reduction ratio of thermal noise caused by the low-pass filter following the S detector is $\sqrt{2f_A/df_W}$; (4) the relative increase in rms noise with a gatewidth twice the burst width is $\sqrt{2}$.

Asymptotic Levels of Envelope Detector Output with Noise

Fig. 11 shows the *dc component of* the envelope detector output as a function of signal-to-noise ratio under the assumption that the receiver has ideal (flat) AGC.

While this output also fluctuates, rectification effects produce limitations which apply even if the fluctuations could be completely ignored. The signal-to-noise ratio here is not identical with S_0/N_W, but, if the burst amplification channel translates nearly all of the timing information, may be roughly equal to it. The reference levels 1 and 0 correspond to the presence or absence of a burst. Curve A represents the average peak value of signal plus noise;[19] removing the signal modifies this to curve B which represents average peak noise only. Curve C represents maximum peak or peak peak values for noise only.

The dc output due to noise only, from an ideal envelope detector which fully follows the envelope, is $\sqrt{\pi/2}\cdot N_{rms}$, where N_{rms} is the rms input noise. When this value equals or exceeds the normal sync amplitude, it is inadequate to distinguish the noise from a high-level noise-free signal. This is indicated by point (1) on the graph.

Many peak detectors have longer time constants than that which permits following noise fluctuations; the gated nature of the sync signal makes ideal envelope detection difficult. For such a case, the dc output from the detector will rise from $\sqrt{\pi/2}\cdot N_{rms}$ toward $4N_{rms}$; this is indicated by point (2).

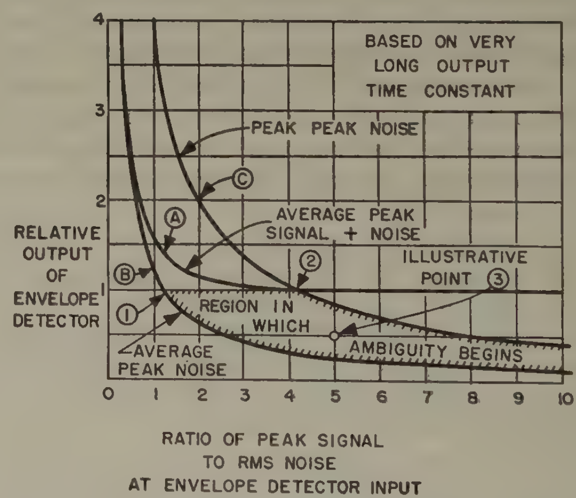


Fig. 11—Graph illustrating failure of envelope detector color killers on thermal noise

If the peak detector is preceded by an amplitude limiter which operates at some fraction of normal burst amplitude, or if the threshold level is at some selected fraction of unity, the failure level may occur for higher

[19] S. Goldman, "Frequency Analysis, Modulation and Noise" McGraw-Hill Book Co., Inc., New York, N. Y., p. 246; 1948. (See eq. 115.)

values of signal-to-noise ratio. Illustrative point (3) shows how a switching level of 1/2 and an intermediate form of detector can lead to an ambiguity threshold at a signal-to-noise ratio of five.

The curves of Fig. 11 can also be used in another way to show how noise can suppress desired signals in non-linear circuits: Consider the variation in output caused by a pulse (such as the burst) having unit amplitude. The differential unidirectional component of output from a properly phased synchronous detector or from the envelope detector in the absence of noise is unity. However, as the relative noise amplitude increases, the signal-to-noise ratio degrades, and the differential output from the envelope detector, as shown by vertical separation between curves A and B, approaches zero.

Thus, nonlinear effects in detectors used in synchronizing systems can cause nonessential limitations of the systems which do not occur with linear synchronous detectors.

Acknowledgment

The author wishes to thank Mr. A. V. Loughren and Mr. C. J. Hirsch of Hazeltine Corporation for their support and encouragement of this investigation. The able assistance of Messrs. H. E. Webb and J. R. White in experimental work is gratefully acknowledged. Thanks are due also for helpful editorial suggestions to the author's associates at Hazeltine laboratories, particularly Mr. Knox McIlwain.

Processing of the NTSC Color Signal for One-Gun Sequential Color Displays*

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Summary—**Circuit techniques for decoding the NTSC color signal to produce three simultaneous color signals, suitable for a three-gun display, are now well known. This paper describes simple circuit techniques for directly processing the NTSC signal at the color receiver to form a signal suitable for a one-gun sequential color display. These circuits fall broadly in two classes, namely, those used to modify the form of color subcarrier signal, and those used to modify the luminance signal. The latter class of circuits generally demodulate some of the color subcarrier signal, and correct the luminance signal in such a manner that constant-luminance operation results.**

Introduction

THE NTSC SIGNAL SPECIFICATIONS describe a band-shared, simultaneous color television signal. Since the signal is simultaneous in nature, either simultaneous or sequential color displays can be used in the color television receiver. In NTSC field tests simultaneous displays of the three-gun, shadow-mask, tricolor tube form were used. Experience has indicated that the practical problems of the particular types of displays used are sufficient to warrant some investigation of other forms of displays.

The use of a form of display giving automatic registration is certainly attractive. The use of a one-gun display is also attractive since it may permit relatively simple and stable production of a neutral grey scale (as compared to the "balancing" of three-gun characteristics required in the three-gun display). While one-gun *simultaneous* displays have been proposed,[1] and appear interesting, the only form of one-gun self-registering display available is a one-gun *sequential* display.[2]

Circuit techniques for decoding the NTSC signal to produce three simultaneous color signals are now well known. Receivers using sequential displays could decode the NTSC signal to obtain three simultaneous color signals and then sequentially sample these signals at the correct timing required by the display. However, such arrangements have a grey-scale tracking problem substantially similar to that of three-gun displays, except here it is three samplers that must be tracked. The purpose of this paper is to describe circuit techniques for directly processing the NTSC signal at the color receiver in order to produce the form of composite signal required by a one-gun sequential display which is switched at a rapid rate. The circuits to be described do *not* require critical matching of components in order to eliminate generation in the receiver of spurious color signals when neutral grey tones are being transmitted.

In the past there has been some tendency to associate the philosophy of color television system design with the characteristics of a particular display which seemed

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[1] British Specification 434,868, September 6, 1935 (to Fernseh); also proposal by G. C. Sziklai, Proc. I.R.E., p. 1200; October, 1951, in "A one-gun shadow-mask color kinescope," by R. R. Law.

[2] As of the present writing the "Chromatron" appears to be an attractive one-gun sequential display. For description see Robert Dressler, "The pdf chromatron—a single or multi-gun tri-color cathode-ray tube," Proc. I.R.E., pp. 851–858; July, 1953. Several other one-gun displays are described in Proc. I.R.E., pp. 1194–1230; October, 1951.

attractive at that moment. It should be noted that most of the NTSC signal specifications are based upon known properties of the eye and not necessarily upon equipment simplifications, and thus are not likely to be affected by a careful consideration of any particular form of display. The wisdom of using a band-shared, simultaneous color signal based upon properties of the eye is further illustrated by this paper since it is shown that relatively simple, stable circuits can be used in a color receiver to process the NTSC signal for several distinctly different forms of sequential-display operation.

Continuous Color-Sequence Display Operation

It is convenient to classify rapid-rate sequential-display operation into two groups, namely, continuous color-sequence and reversing color-sequence operation. Continuous color-sequence-display operation means operation so that the beam of the display device can successively excite the color phosphors in a simple, repeating color sequence, such as *GRBGRB*, and so forth. Performed at a rapid rate, such operation has been called dot-sequential operation. Reversing color-sequence operation differs in that the beam of the display device can successively excite the color phosphors in a color sequence which reverses in order before the entire sequence of colors is repeated, such as *BGRRGBBGR*, and so forth.

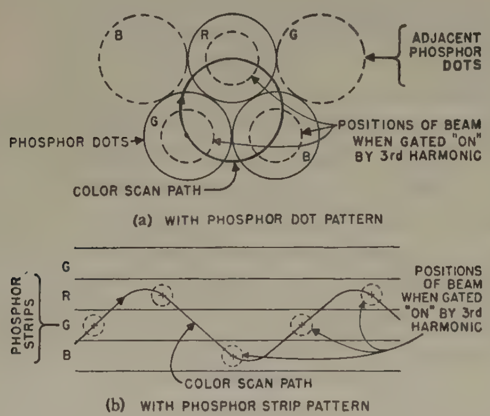

Fig. 1—Display gating for continuous color-sequence operation.

Continuous color-sequence-display operation can be practiced with displays having the color phosphors arranged either in dots or in strips. Dot-sequential operation of the one-gun, shadow-mask tri-color tube (using color phosphors arranged in a dot pattern) has been described in the literature.[3] By the use of a rotating magnetic field at the color-switching frequency, the "angle of approach" of the cathode-ray beam to the shadow-mask plate is made to follow a conical path. The resulting "shadowed" beam travels a circular path through the phosphor-dot clusters as shown in Fig. 1(a), and by "gating" with a third harmonic signal the beam can excite each phosphor dot near its center.

Continuous color-sequence operation could be practiced with displays having the color phosphors arranged in strips, by using a step or sawtooth color-switching signal. However, because of power requirements, sinusoidal switching is preferable. With a sinusoidal-switching signal the beam would normally excite the color-phosphor strips in the order *GRGBGRGB*, and so forth, assuming green as the color phosphor excited when the switching signal is zero. This can be modified to a simple continuous color-sequence operation by gating the beam with a properly-phased third-harmonic signal, as shown in Fig. 1(b). Dot-sequential operation of the type just mentioned has been previously described in the literature.[4] It is interesting to note that if the phase of the third-harmonic gate is reversed in the operation in Fig. 1(b), the color sequence will also reverse (being *BRG* instead of *GRB*). The equivalent does not occur with the operation in Fig. 1(a).

Direct Application of NTSC Signal

An NTSC signal might be directly applied to the intensity-control electrode of a one-gun, continuous color-sequence display employing a color-switching frequency equal to and synchronized with the NTSC subcarrier frequency (3.6 mc) and employing the same color sequence (*GRB*). Of course, incorrect brightness and chromaticity will be reproduced, since a dot-sequential signal is required for correct operation of such a display. Also the benefits of constant-luminance operation are not obtained with such a receiver.[5] However, by suitably adjusting the phase of the display sampling and the relative amplitude of the chrominance signal as applied to the display, certain critical colors can be rather accurately reproduced.

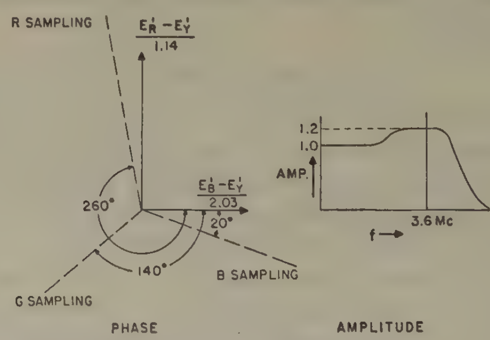

Fig. 2—Operating conditions for direct application of NTSC signal to a dot-sequential display.

Colors approximately along the "wide-band orange-cyan axis" (corresponding to colors reproduced when E_Q' of the NTSC signal is approximately zero) can be reproduced quite accurately by sampling for *B*, *G*, and *R* at -20 degrees, -140 degrees and -260 degrees re-

[3] "General description of receivers for the dot-sequential color television system which employ direct-view tri-color kinescopes," *RCA Review;* June, 1950. Also Law, *op. cit.*

[4] P. K. Weimer and N. Rynn, "A 45-degree reflection-type color kinescope," Proc. I.R.E., particularly pp. 1207 and 1208; October, 1951.

[5] For a description of these benefits see B. D. Loughlin, "Recent improvements in band-shared simultaneous color-television systems," Proc. I.R.E., p. 1270, item G; October, 1951.

spectively, and in that time sequence (assuming NTSC to have $B-Y$ at 0 degrees and $R-Y$ at -270 degrees), and by boosting the chrominance signal relative to luminance signal so that relative transmissions are 1.2 to 1.0. Fig. 2 illustrates this condition of operation. A plot on the CIE diagram of the brightness and chromaticity errors expected by such operation is shown in Fig. 3. The arrows shown start at the intended chromaticity and end at the reproduced chromaticity. In calculating this data, it has been assumed that the gamma exponent of the display is 2.2 and that the NTSC signal is gamma-corrected according to current practice, that is, that the primary color-signal voltages E_G, E_R, and E_B are gamma-corrected according to a 1/2.2 power law.

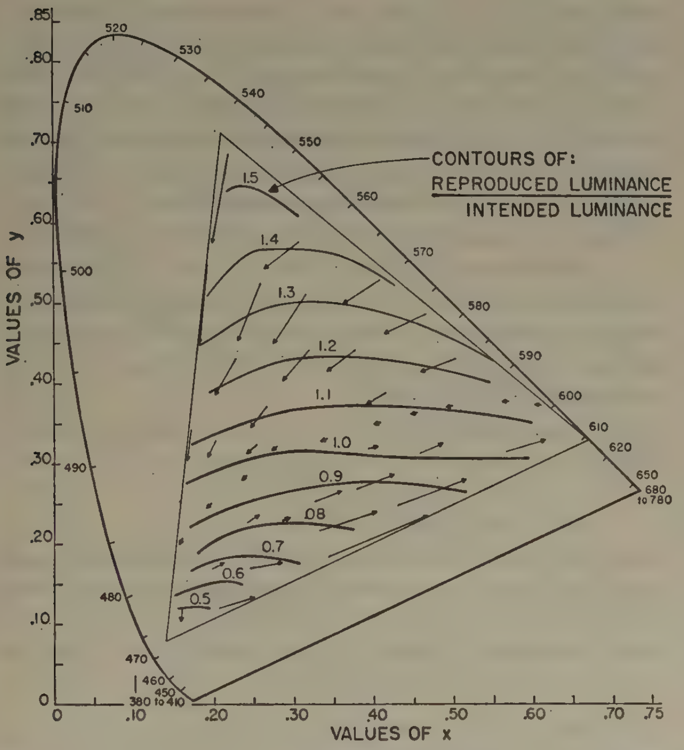

Fig. 3—Colorimetric errors from direct application of NTSC signal to a dot-sequential display.

Processing of NTSC Signal at Receiver

If the NTSC signal is modified *at the receiver* to a dot-sequential signal the dot-sequential displays mentioned previously can be used to give the intended colorimetric reproduction. Also the benefits of constant-luminance operation will be obtained with such a receiver. To clarify the necessary operations for converting from one signal to another, the signal characteristics will now be reviewed.

The NTSC signal contains a monochrome component of $E_Y'=0.59\ E_G'+0.30\ E_R'+0.11\ E_B'$, and a chrominance of subcarrier component usually described as a pair of quadrature components, such as $(E_R'-E_Y')/1.14$ and $(E_B'-E_Y')/2.03$. However, the subcarrier can just as accurately be described by a set of three vector components having amplitudes proportional respectively to E_G', E_R', and E_B'. These equivalent representations of the NTSC chrominance signal are shown in Fig. 4(a).

The signal desired for a dot-sequential display has a monochrome component of $E_M'=1/3\ E_G'+1/3\ E_R'+1/3\ E_B'$, and a subcarrier which is generally described as a symmetrical set of three vector components having respective amplitudes of $2/3\ E_G'$, $2/3\ E_R'$ and $2/3\ E_B'$.[6] This subcarrier signal can also be described by a set of $(E_R'-E_Y')$ and $(E_B'-E_Y')$ components for convenient comparison with the NTSC signal. To make such a transformation, consider adding $-2/3\ E_Y'$ to each vector of the symmetrical set of $2/3\ E_G'$, $2/3\ E_R'$ and $2/3\ E_B'$ vectors to give a symmetrical set of $2/3\ (E_G'-E_Y')$, $2/3\ (E_R'-E_Y')$, $2/3\ (E_B'-E_Y')$ vectors. This is no change since the set of $-2/3\ E_Y'$ vectors add to zero. Then using the relation $E_G'-E_Y'=-0.51\ (E_R'-E_Y')-0.19\ (E_B'-E_Y')$ the (E_G-E_Y') vector is replaced by $(E_R'-E_Y')$ and $(E_B'-E_Y')$ components.[7] The total $(E_R'-E_Y')$ and $(E_B'-E_Y')$ components are found by vector addition giving the equivalent subcarrier signal illustrated in Fig. 4(b).

The Y to M Converter: The NTSC monochrome signal E_Y' can be modified to E_M' by the addition of a signal having the composition of $E_M'-E_Y'=-0.25\ E_G'+0.03\ E_R'+0.22\ E_B'$. This signal will be recognized as having the same form as the color-difference signals which modulate the NTSC chrominance signal, specifically $E_M'-E_Y'$ goes to zero when transmitting reference white (CIE Illuminant C). Signals of this form can be obtained by synchronous detection of the NTSC chrominance signal at a certain phase and with a certain gain.

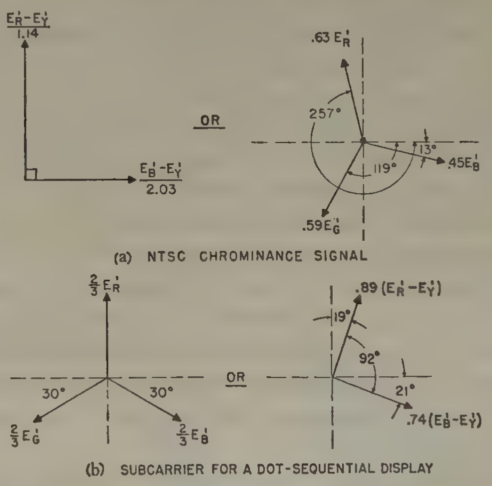

Fig. 4—Subcarrier vector diagrams.

The desired $E_M'-E_Y'$ signal can be found in terms of $E_R'-E_Y'$ and $E_B'-E_Y'$ by the following procedure:

$$E_M' - E_Y' = 1/3\,(E_G' - E_Y') + 1/3\,(E_R' - E_Y') + 1/3\,(E_B' - E_Y');$$

[6] For a description of the dot-sequential signal in terms of monochrome and subcarrier components see Loughlin, p. 1265; *op. cit.*

[7] For a derivation of this relation see C. J. Hirsch, W. F. Bailey, and B. O. Loughlin, "Principles of NTSC compatible color television," *Electronics*, p. 90; February, 1952.

but for NTSC specifications:

$$E_G' - E_Y' = -0.51\,(E_R' - E_Y') - 0.19\,(E_B' - E_Y');$$

thus:

$$E_M' - E_Y' = 1/3\,(1 - 0.51)(E_R' - E_Y') + 1/3\,(1 - 0.19)(E_B' - E_Y').$$

This can be put in terms of the NTSC chrominance components:

$$E_M' - E_Y' = 0.19\left(\frac{E_R' - E_Y'}{1.14}\right) + 0.55\left(\frac{E_B' - E_Y'}{2.03}\right).$$

This corresponds to 0.58 times the modulation components of the NTSC chrominance signal at an angle of +19 degrees, as illustrated by the vector diagram relations in Fig. 5. Thus, it will be seen that E_Y' can be converted to E_M' by the addition of a color-difference signal obtained by synchronous detection at +19 degrees with a gain of 0.58.

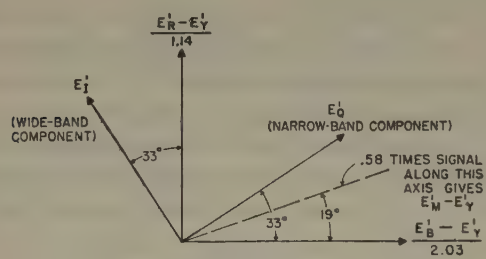

Fig. 5—Vector relations for $E_M' - E_Y$.

A block diagram of an NTSC signal processing circuit which uses a Y to M converter, operating as just described, is shown in Fig. 6. The NTSC monochrome signal is translated through a shunt 0–3 mc amplifier, which may require a delay circuit so that all shunt paths have the same delay. The subcarrier signal is translated through the subcarrier modifier, to be described later, and a suitable component of the subcarrier is detected, in the Y to M converter, to give an $E_M' - E_Y'$ signal. For simplicity, double side-band operation for the subcarrier channel for ±600 kc is illustrated. Wider bandwidth might be used; however, the circuits for detecting $(E_M' - E_Y')$ can be restricted in bandwidth since, as seen from Fig. 5, the signal consists mainly of the narrow-band E_Q' component and contains relatively little of the wider-band E_I' component.

One aspect of the Y to M converter which should be noted is that it permits constant-luminance operation of a dot-sequential display.[8] It can be viewed as producing a luminance correction signal $(E_M' - E_Y')$ which when added to E_Y' cancels the luminance change produced by the subcarrier signal applied to a dot-sequential display. (This is only a first order correction similar to that practiced in current receivers and it ignores the nonlinear characteristics of the cathode-ray tube gun.) Or, another point of view is as follows: the subcarrier demodulation effect in the Y to M converter is effectively applied equally and in the same phase to all three primary color phosphors and this adds to the symmetrical subcarrier demodulation effects in the dot-sequential display so as to produce the equivalent of the desired over-all asymmetrical demodulation effect which gives constant-luminance operation.

The Subcarrier Modifier: The color composition of the subcarrier signal can be modified to that desired for a dot-sequential display by the addition of a reversed phase-sequence subcarrier signal (i.e., a subcarrier in which the colors vs. phase occur in opposite sequence.) For example, if a subcarrier in which the $(E_R' - E_Y')$ component lags the $(E_B' - E_Y')$ components is added to the NTSC signal in which $(E_R' - E_Y')$ leads $(E_B' - E_Y')$, then the amplitude and phases of $(E_R' - E_Y')$ and $(E_B' - E_Y')$ will be modified in opposite directions. This effect is illustrated by the vector diagrams of Fig. 7. The resulting subcarrier signal is seen to have modified amplitude and phase characteristics vs. color.

The above operation can be conveniently performed in a modulator-amplifier in which the NTSC chrominance signal is heterodyned with a second harmonic reference subcarrier (7.2 mc) as illustrated in the block diagram of Fig. 6. The operation of this arrangement can be illustrated as follows:

The transfer (gain) characteristic of the modulator-amplifier is assumed to be of the form

$$1 + 2m \cos (2\omega t + \theta_2),$$

where the first term represents the average gain and the second term represents the gain variation due to the second harmonic heterodyning signal (note $m = 1$ for narrow angle modulator). Assuming the input signal to be: $A \cos (\omega t + \theta)$, the output signal is:

$$A \cos (\omega t + \theta) + 2mA \cos (\omega t + \theta) \cos (2\omega t + \theta_2).$$

The second term can be expanded to:

$$mA\left[\cos (3\omega t + \theta + \theta_2) + \cos (\omega t + \theta_2 - \theta)\right].$$

The first term within the bracket is ignored by frequency selectivity, giving a total useful output of:

$$A\left[\cos (\omega t + \theta) + m \cos (\omega t + \theta_2 - \theta)\right].$$

It will be noted that the useful output of such a modulator-amplifier contains the original subcarrier plus a reversed phase-sequence $(-\theta)$ subcarrier of controllable amplitude (mA) and static phase shift (θ_2). Thus by suitably adjusting m and θ_2 the subcarrier color characteristics can be modified as desired.

From a comparison of the two subcarrier signals given in Fig. 4 it will be noted that, outside of the static phase shift of about 20 degrees, the modification consists mainly of boosting the $(E_B' - E_Y')$ component relative to the $(E_R' - E_B')$ component. Thus the re-

[8] An early form of circuit for permitting constant-luminance operation with a one-gun display was proposed by D. Richman of Hazeltine Corp. in unpublished material.

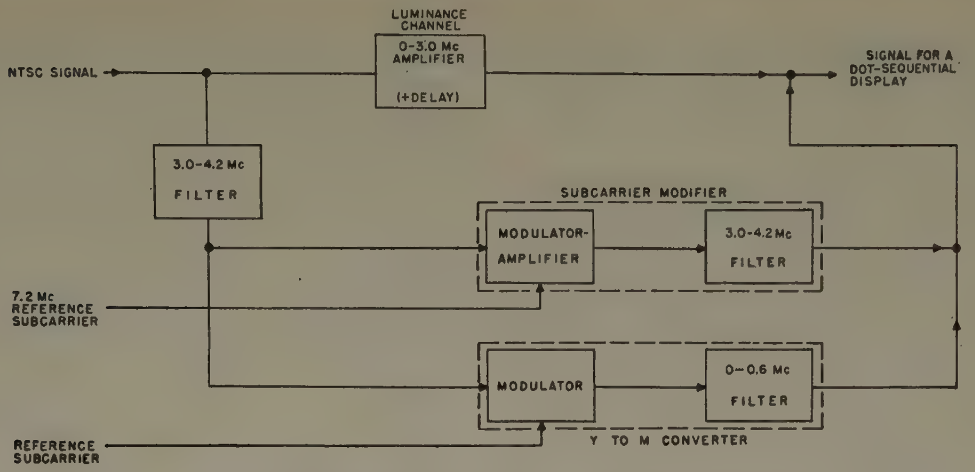

Fig. 6—Processing of NTSC signal for a dot-sequential display.

versed phase-sequence subcarrier which is added should have $(E_B'-E_Y')$ in phase and $(E_R'-E_Y')$ 180 degrees out of phase with respect to the original NTSC signal. Actually, the added components should be just slightly misphased so that the net $(E_R'-E_Y')$ and $(E_B'-E_Y')$ components are slightly more than 90 degrees apart.

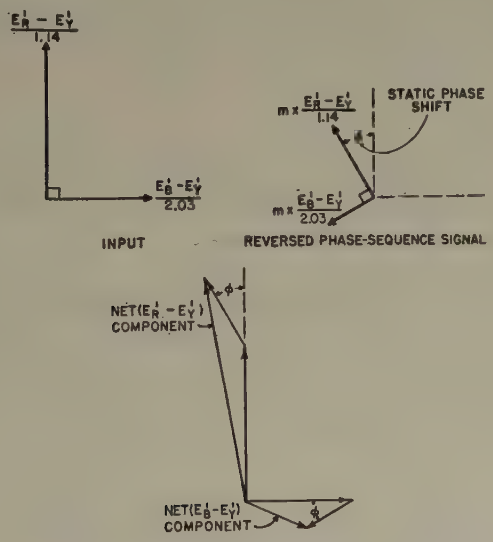

Fig. 7—Subcarrier modification by addition of reversed phase-sequence subcarrier.

The exact solution for the desired modulator-amplifier characteristics gives $m=0.19$ and the angle between the $(E_B'-E_Y')$ components of the direct and reversed phase-sequence subcarriers as -4.9 degrees. These conditions and the resulting signals are illustrated in Fig. 8. For a translation gain of unity the net output signal is 0.8 times the desired subcarrier signal. Thus the subcarrier modifier channel should have a gain of 1.25 relative to the shunt monochrome channel.

When combined with the Y to M converter the subcarrier modifier just described gives a complete arrangement (shown in Fig. 6) for processing the NTSC signal for a dot-sequential display operating at a color-switching frequency equal to the NTSC subcarrier frequency. With such an arrangement the colorimetric properties of the over-all receiver are equivalent to those of the simultaneous three-gun receivers such as used during NTSC field tests. However, due to the dot-sequential operation of the picture tube at a 3.6-mc rate a crawling, luminous dot pattern tends to be produced at all times (including when reproducing neutral greys). This might be reduced in visibility by "soft focus," which, of course, will also reduce the over-all luminance detail. Or the display might be operated at a higher color-switching frequency (such as 7.2 mc), and the NTSC chrominance signal could then be heterodyned in the receiver to the higher frequency (such as by heterodyning the received 3.6-mc signal with a 10.8-mc reference signal).

It should be noted that the processing circuits of Fig. 6 might be simplified by combining functions. For example, the subcarrier modifier channel could be arranged also to translate the luminance signal. However, these operations have been shown here separately for clarity of explanation.

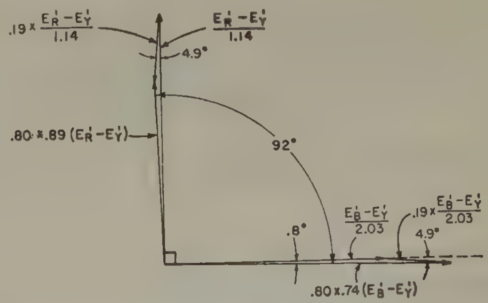

Fig. 8—Vector diagram of NTSC subcarrier processing for a dot-sequential display.

Reversing Color-Sequence Display Operation

The second class of rapid-rate sequential display operation that will be considered is reversing color-sequence operation. As previously mentioned, this means that the beam of the display device can successively excite the color phosphors in a color sequence

which reverses in order before the entire sequence of colors is repeated. While such operation is possible with displays having the color phosphors arranged either in dots or in strips, it will be described here in reference to the phosphor strip arrangement.

For displays having the color phosphors arranged in strips, normal sinusoidal color switching will excite the colors in the order *GRGBGR*, and so forth (assuming G as the "undeflected" color). However, for equal total excitation of the three color phosphors, the red and blue "dwell-times" need to be twice the "dwell-time" on the green phosphor, since green is excited twice as often. Thus we might conveniently consider that each R and each B, in the previously mentioned color sequence, is really two successive R's and B's respectively. With this point of view, the color sequence for sinusoidal switching with a phosphor strip display is *GRRGBBGRR*, and so forth. The accuracy of the terminology "reversing color sequence" now becomes apparent.

The Six-Sample Color Cycle

The essentials of reversing color-sequence operation can be illustrated by considering a phosphor-strip display having sinusoidal color switching and with "gating" of the display beam by a sixth harmonic of the color-switching rate. The resulting operation is illustrated by Fig. 9, and it is apparent that the display beam excites the color phosphors in the reversing color sequence previously stated. The over-all operation of the display is seen to be equivalent to an array of six samplers, equally spaced in time (60 degrees apart at fundamental frequency) and in which the first and fourth samplers excite green, the second and third excite red, and the fifth and six excite blue. This can be further simplified by considering the equivalent demodulation effect of a single sampler, and then evaluating the combined effect of the six samplers.

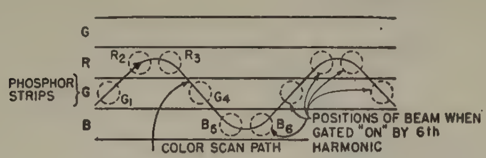

Fig. 9—Operation of phosphor-strip display with a six-sample color-cycle.

The output of a single sampler is the input signal multiplied by, or modulated by, the sampling waveform. Thus, if the input signal is E, and the Fourier series analysis of the sampling waveform is:

$$1+2m_1 \cos(\omega t+\theta_1)+2m_2 \cos(2\omega t+\theta_2)+\cdots,$$

then the output signal is:

$$E+2m_1 E\cos(\omega t+\theta_1)+2m_2 E\cos(2\omega t+\theta_2)+\cdots.$$

In this equation the first term corresponds to translation of the input signal at unit gain, the second term corresponds to synchronous detection at the fundamental sampling frequency (with a gain of m_1 and at an angle of θ_1 from a cosine function), and the third term corresponds to synchronous detection at the second harmonic sampling frequency (with a gain of m_2 and at an angle of θ_2 from a cosine function).[9]

Using the above equivalent relations for a single sampler, it will be noted that the net effect of the six samplers arranged to sample 60 degrees apart as previously mentioned is to translate the monochrome signal, synchronously detect any signal at fundamental frequency in accordance with the vector diagram relations of Fig. 10(a) and synchronously detect any second harmonic signal in accordance with Fig. 10(b). In these vector diagrams green is assumed at 90 degrees (i.e. in phase with a cosine function, thus making the color switching voltage be a size function, or at zero degrees), and the sampling pulse is assumed to be symmetrical so that $\theta_2=2\theta_1$ for each sampler. From Figs. 10(a) and (b) it is noted that the net red and blue fundamental frequency detection actions are equal and opposite being along the 0–180 degree axis, and the net green fundamental frequency detection is zero. On the other hand, the net red and blue second harmonic detection actions are equal and at 270-degree phase, while the net green detection action is equal to twice the red or blue detection action and is at 90-degree phase.

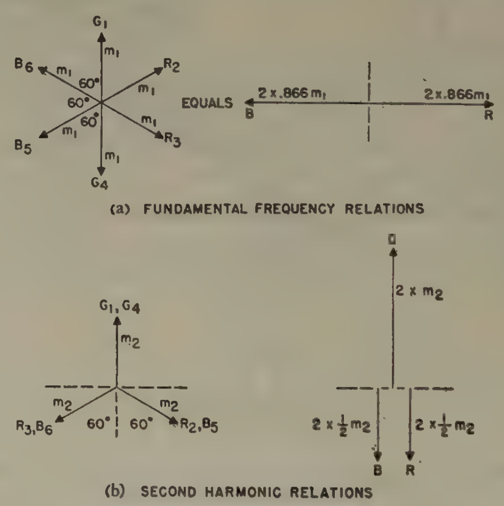

Fig. 10—Vector diagram of equivalent synchronous detector action of six-sample operation.

It is now seen that with this six-sample operation the display effectively detects along only *one* axis (0–180 degrees) at fundamental subcarrier frequency and along only *one* axis (90–270 degrees) at second harmonic frequency. Thus if the NTSC color signal is directly applied to such a six-sample display operating with a switching frequency equal to the NTSC subcarrier frequency, a two-color picture should result. Specifically, no variation in the direction of green or minus green

[9] For a similar comparison of samplers and modulators see footnote reference 5, p. 1265.

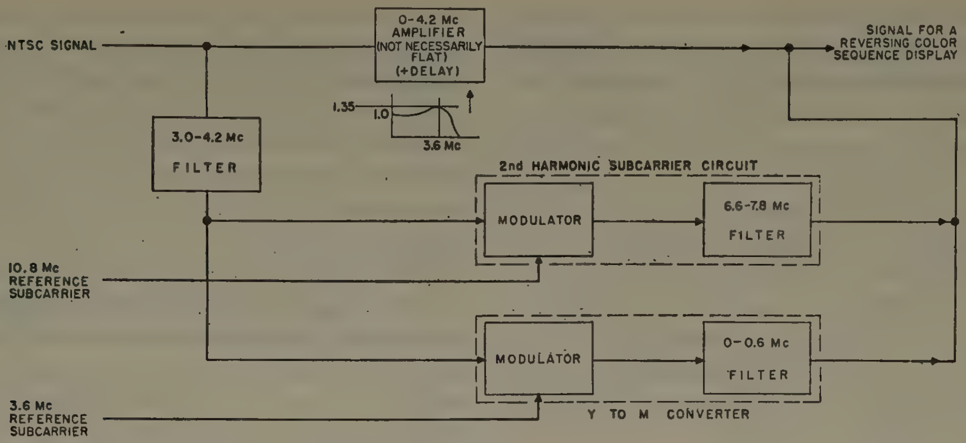

Fig. 11—First-order processing of NTSC signal for a reversing color-sequence display.

should be seen. However, the above has ignored the effects of a nonlinear electron-gun, and actually some rectification of fundamental frequency signals along the 90–270 degree axis results. Such rectification is not phase-sensitive, so that a desaturated green is produced for either phase of component along this axis.

First-Order Solution to Three-Color Operation

If the rectification effect just cited is ignored for the moment and only the first-order solution for decoding is considered, a relatively simple arrangement can be derived to obtain three-color operation. Assume that the effective sampling waveform of the display has fundamental and second-harmonic components of amplitudes $2m_1$ and $2m_2$, relative to a dc component of unity, as previously mentioned. Then, using vector diagrams of Figs. 10(a) and (b), the first-order solution of detection efficiency can be evaluated for each primary color. These are tabulated below, and are expressed relative to a monochrome translation efficiency of unity (i.e., all quantities of Fig. 10(a) and (b) are divided by 2 since the net monochrome translation for each pair of G, R or B samples is 2).

DISPLAY DECODING EFFICIENCY

Primary Color	Monochrome Component	Fundamental Cosine	Fundamental Sine	Second-Harmonic Cosine	Second-Harmonic Sine
Green	1	0	0	m_2	0
Red	1	0	$0.866m_1$	$-0.5m_2$	0
Blue	1	0	$-0.866m_2$	$-0.5m_2$	0

Now, if we call the amplitude of the *sine* component of the fundamental equal to a_1, the amplitude of the *cosine* component of the second harmonic equal to a_2, and the monochrome component equal to E_M', then the net low-frequency outputs resulting from decoding in the display are:

$$\text{Green} = E_M' + m_2a_2,$$
$$\text{Red} = E_M' + 0.866m_1a_1 - 0.5m_2a_2,$$
$$\text{Blue} = E_M' - 0.866m_1a_1 - 0.5m_2a_2.$$

Assuming that the desired Green, Red, and Blue outputs due to decoding are E_G', E_R', and E_B', the resulting equations can be solved for E_M', a_1 and a_2, giving:

$$E_M' = 1/3\,E_G' + 1/3\,E_R' + 1/3\,E_B',$$
$$0.866m_1a_1 = 1/2\,E_R' - 1/2\,E_B',$$
$$m_2a_2 = 2/3\,E_G' - 1/3\,E_R' - 1/3\,E_B'.$$

Thus as far as first-order effects are concerned, correct colorimetric reproduction can be obtained with this reversing-sequence, six-sample color cycle operation if the monochrome component, fundamental frequency *sine* component, and second-harmonic *cosine* component are as described by these equations. As far as these first-order effects are concerned, the fundamental frequency *cosine* component and second-harmonic *sine* component can have any value since they are averaged out.

The steps in processing the NTSC signal to meet the signal requirements just outlined are as follows:

a. Apply the complete NTSC signal to the display intensity control electrode, with the display color-switching frequency equal to the NTSC subcarrier frequency and with the phase so adjusted that the component of the NTSC signal proportional to $(E_R'-E_B')$ appears as a sine component.
b. Use the previously described Y-to-M converter to develop E_M' from E_Y'.
c. By heterodyning the NTSC chrominance signal with either a fundamental or a third-harmonic subcarrier, develop a second-harmonic NTSC chrominance signal, and apply to the display with such a phase that the component of the NTSC signal proportional to $(E_G'-1/2E_R'-1/2E_B')$ appears as a cosine component.
d. Adjust the amplitudes of the fundamental and second-harmonic chrominance signals relative to the monochrome signal to obtain the correct saturation. This is a function of the effective sampling angle, which determines constants m_1 and m_2.

The above operation is illustrated by the block diagram of Fig. 11. The correct angles of the NTSC chrominance signal for obtaining the desired color-difference

components are shown in Fig. 12. For a flat pass-band giving unity chrominance to luminance signal gain, the components obtained from the NTSC subcarrier are 0.43 $(E_R'-E_B')$ and 0.56 $(E_G'-1/2E_R'-1/2E_B')$. Thus,

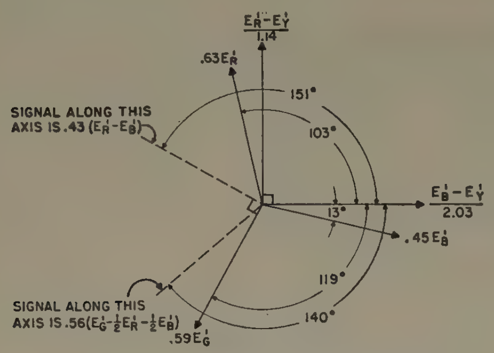

Fig. 12—Vector relations of components desired by reversing color-sequence display.

for effectively narrow-angle sampling, which gives $m_1=m_2=1$, the relative gain required in the fundamental channel is 1.35 times and in the second-harmonic channel is 1.2 times.

the two samples for each color. The components which are ignored by this solution are "quadrature" components which increase one sample and decrease the other sample. Voltage-wise the effect of these "quadrature" components average out; however, due to the nonlinear characteristic of the gun the light effects do not average out, instead some rectification results, as previously mentioned.

The rectification effects just cited can be eliminated if the "unused" quadrature components are eliminated. Such a composite signal proportioned for narrow-angle sampling and containing only the desired fundamental and second-harmonic component will have the property that it passes through E_G', E_R', E_R', E_G', E_B' and E_B' at the six successive sampling points. This is illustrated in Fig. 13. It is apparent that with this signal, intended colorimetric reproduction can be obtained from a display having a nonlinear electron-gun characteristic.

Processing of the NTSC signal to provide this accurate six-sample operation requires effective selection of one subcarrier axis, and effective elimination of the

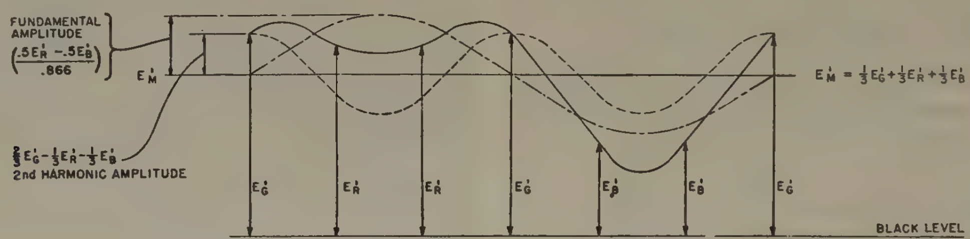

Fig. 13—Waveform for accurate narrow-angle six-sample operation.

It is interesting to consider the operating conditions that result if the sixth-harmonic gating signal is removed. This then gives substantially the equivalent of 60 degrees sampling in the terminology used above, due to the traverse of the color scanning path across the respective color phosphor strips, with the two red samples and the two blue samples respectively merging so as to produce one wide 120-degree red sample and one wide 120-degree blue sample. As far as first-order effects are concerned, the relations given above would still hold except that $m_1=0.96$ and $m_2=0.83$ for 60-degree sampling. Of course, second-order effects which are not evaluated by the above become more important and produce more significant color contamination with wide-angle sampling. However, an accurate evaluation of these second-order effects additionally requires consideration of the nonlinear characteristic of the electron gun and this reduces the color contamination since it tends to effectively sharpen the composite signal into narrower pulses. Thus, this wide-angle operation, in which all gating automatically occurs in the picture tube, should not be ignored.

Accurate Six-Sample Operation

In the first-order solution just considered the net green, red, or blue output is evaluated as the average of

quadrature axis. This "axis selection" operation can be obtained by the subcarrier modifier previously described. If the modulator-amplifier operates as a narrow-angle modulator or sampler (i.e. so $m=1$ in the equation given for modulator-amplifier transfer characteristic), then the reversed sequence subcarrier produced by heterodyning with the second harmonic will have the

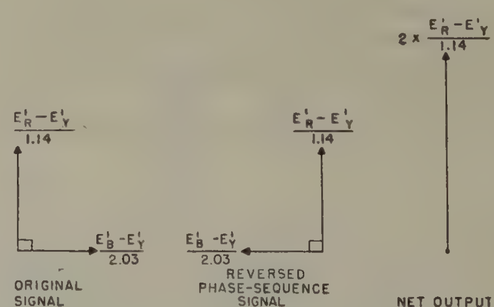

Fig. 14—Vector diagram for $(E_R'-E_Y')$ axis-selector.

same amplitude as the translated original subcarrier. The combination of these two equal amplitude, but opposite sequence, subcarriers will add along one axis and cancel along the quadrature axis, thus acting as the desired "axis-selector." Fig. 14 further illustrates this operation. Another point of view for such an axis-selec-

tor is that it is a narrow-angle sampler which connects the input signal to the output circuit twice per cycle for short intervals of time and thereby ignores the quadrature component which is passing through zero at these instances.

By combining the axis-selector just described with the circuit of Fig. 11, a complete arrangement for processing the NTSC signal to provide accurate six-sample operation is obtained. Such an arrangement is illustrated in Fig. 15. Simplification of this circuit is conceivable by combining some of the functions, however, the functions are shown here as being performed separately for simplicity of explanation.

of the type which do *not* require a critical balance for satisfactory operation. Specifically, the subcarrier is always produced in these circuits by direct translation or by direct heterodyning with the input chrominance subcarrier, and thus when simple frequency selection is employed in the modulators, the output subcarrier always goes to zero when the input subcarrier goes to zero, independently of any critical balanced operation. This means that when zero subcarrier is transmitted a neutral grey scale is reproduced having a color determined only by the display phosphor characteristics, the relative "dwell-time" on the three phosphors, and any small subcarrier signal which may have been pur-

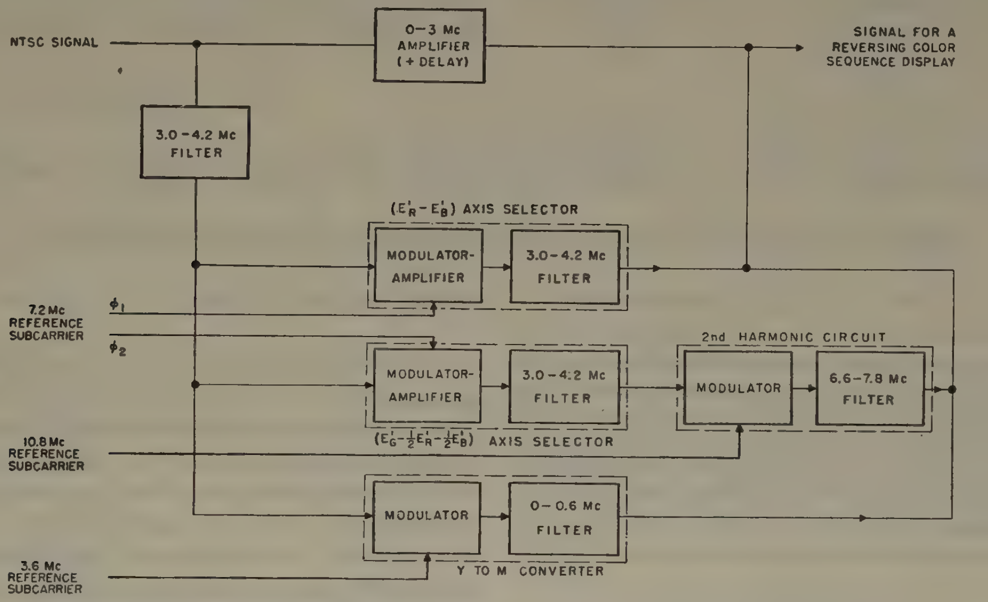

Fig. 15—Processing of NTSC signal for accurate six-sample operation.

The arrangement just described can reproduce the intended scene from an NTSC signal with a colorimetric accuracy at least equivalent to that obtainable with the three-gun simultaneous displays used during NTSC field tests. Constant-luminance operation is also obtained, through the *Y*-to-*M* converter. In addition, this arrangement comes closer to simulating simultaneous reproduction than does the continuous color-sequence display operated at the same color-switching frequency. This is true since for a 3.6-mc switching frequency green is sampled at a 7.2-mc rate, thus giving substantially the equivalent of a simultaneous green picture but having stationary 7.2-mc dots which are, for all practical purposes, invisible. Also, due to the lower resolution of the eye to red and blue detail in the composite picture, the 3.6-mc crawling luminous dot pattern present in the red and blue picture is reduced in visibility, thus giving an approach to simultaneous reproduction for these colors also.

Some Practical Considerations

The circuits described which process the NTSC subcarrier signal to the form desired by the display are all posely added to the display to slightly modify the color of "white." It seems likely that such an arrangement may prove to be quite stable on color balance.

In order to obtain pictures with adequately high brightness at a reasonable cost when using a sequential display, good efficiency of light output vs. cathode-ray-tube beam current is rather important. The shadow-mask type color tube has rather poor efficiency due to the small percentage of beam current which actually strikes the color phosphors. Also, the one-gun version of the shadow-mask tri-color tube previously described has registration problems which are similar to those of the currently used three-gun shadow-mask tri-color tubes. However, at the present writing a tube currently available which looks particularly attractive for a one-gun sequential display is the phosphor-strip tri-color tube known as the "Chromatron."[10] This tube has a good light efficiency since practically all of the beam current strikes the color phosphors, has automatic registration (for one-gun version) due to color switching near phosphor screen, and is available in a one-gun version.

[10] See footnote reference 2.

The "Chromatron" has several disdvantages which must be weighed against its advantages. First, considerable power is required for color switching at a 3.6-mc rate. This is not so much of a disadvantage because of dc power requirements (since most of this is saved elsewhere in the color set), but it may present a radiation problem. The second disadvantage is the line structure of presently available tubes which, while apparently satisfactory in the grey areas of the picture, is definitely noticeable in saturated red areas. However, at present writing, this tube appears attractive when used with the type of circuits described in this paper for reversing color-sequence display operation which gives a substantially simultaneous picture when using a 3.6-mc color switching frequency.

Conclusions

Relatively simple and stable circuits have been described for processing of the NTSC color signal for one-gun sequential displays operated as either continuous color sequence or reversing color-sequence displays. Some of the circuits described are at least as simple as many of the decoders currently used with three-gun simultaneous displays, and are stable forms of circuits since the processed subcarrier signal automatically goes to zero when the input subcarrier goes to zero on white, independently of any critical balance adjustments in the receiver. Also, the circuits described permit first-order constant-luminance operation of the color receiver, substantially as has been practiced at NTSC field tests, and permit intended colorimetric reproduction.

Compatible Color Picture Presentation with the Single Gun Tricolor Chromatron*

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Summary—**Techniques suitable for operation of the single-gun tricolor Chromatron tube with present-day compatible color television standards are presented. The experimental circuits constructed to explore two methods of use are described, along with the results of practical testing of these circuits. A method of correcting for circuit nonlinearity which assures color balance under all situations of light level is discussed, in connection with the problem of adding color-difference information directly into the gun of the picture tube.**

Introduction

THE WIDELY ACCEPTED system of color television as proposed by the National Television System Committee presents the designer of terminal equipment with a high quality compatible signal. Wide flexibility of receiver design is permitted, since the signal contains simultaneous information as to the brightness, hue, and saturation required at each point in the picture. Since these quantities are continuously available, they may be used in any desirable manner to actuate various types of reproducers. In this paper we shall discuss two methods for translating an NTSC signal into forms suitable for presentation with the Chromatron or Lawrence color tube.

This type of tricolor viewing tube has been described in some detail in a previous issue of this publication.[1] Briefly, it uses a single electron beam, which can be focused to any one of three sets of phosphor strips. Each of the three sets of strips is made up of materials which fluoresce in one of the primary colors (red, blue, or green) under electron bombardment. The phosphor strips are arranged on the viewing surface in the sequence red, green, blue, green, etc. The color being displayed at any instant is independent of beam position and determined only by the relative potential of the color control electrodes. The operation of the tube may be understood by examination of Fig. 1. It will be seen that for each of the red and blue phosphor strips there is a grid wire in electron optical alignment with the strip. All of the wires corresponding to red strips are brought to one external terminal. Those corresponding to blue strips are brought to another terminal. An accelerating potential, of correct magnitude relative to the incident beam energy, is applied between the entire grid and the phosphor plate. Under this condition, a beam of electrons incident upon the grid plane will be focused to the center (green) strips. If a potential difference of proper magnitude is applied between the two sets of grid wires, the beam will be deflected to the strip lying under the more positive wire. Generally, the tube is arranged to operate with the strips in a horizontal array, such that the raster lines are approximately parallel to the phosphor strips. It is not necessary that any relationship between scanning lines and phosphor lines be maintained.

We have explored two methods of presentation of a decoded NTSC signal with the Chromatron. The first method consists of deriving signals of the form E_r-E_y, E_g-E_y, E_b-E_y to each of which is added the E_y signal, giving three simultaneous signals, the amplitude of which corresponds to the instantaneous light output required in each primary color. The resulting three signals are then processed suitably for application to the tube. In the second method, the signals corresponding to color-difference information are processed in a similar

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[1] R. Dressler, "The PDF Chromatron—a single or multi-gun tri-color cathode-ray tube," Proc. I.R.E., vol. 41, pp. 851–858; July, 1953.

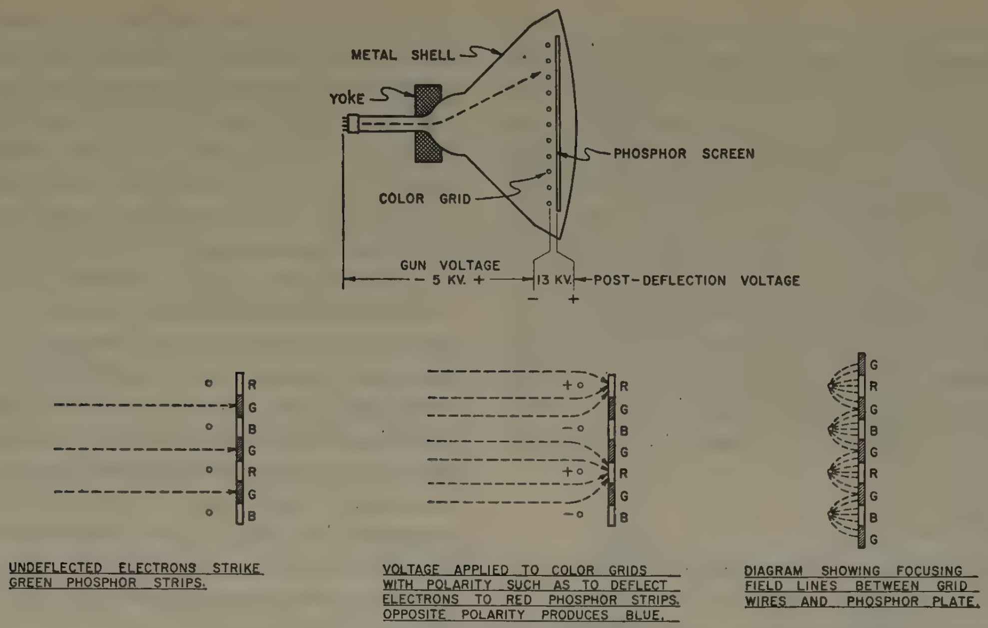

Fig. 1—Sketch of Chromatron.

way, but the addition of the brightness information takes place within the electron gun. For the sake of simplicity, we will discuss the former scheme first.

Operation with Simultaneous Color Signals

Given three simultaneous signals, representing the instantaneous brightness of each of the three primary colors, two basic circuit functions must be performed in order to display a picture on the single-gun tube. One of these is the switching operation, in which the beam is caused to oscillate rapidly over a set of three-color phosphor strips. The second is the gating operation, in which the incoming video information is combined to produce a single video signal, which is proportional to the primary color voltages one at a time in the proper sequence.

Choice of Switching Frequency

In operating a switchable color reproducer one must choose a sequence and rate at which bits of information in each of the primary colors will be presented. In making this choice the sampling frequencies must be so chosen that none of the information in the original signal will be lost, and also that spurious low-frequency beat signals will not be introduced. In sampling any one channel of color information delivered to the gate circuits there is a signal of narrow 1.5-mc bandwidth corresponding to that color plus a wide-band (4-mc) signal common to all channels.

As far as information not common to all channels is is concerned, a sampling frequency may be chosen on the basis of the following considerations. One may regard the appearance of a dot of colored light as an amplitude sample of the corresponding color signal taken at the instant the dot appears. Information theory provides a theorem relating the minimum rate at which such samples must be presented to the bandwidth of the signal to be time-quantized, if the loss of information and the production of low-frequency beats are to be avoided.

This relationship may be derived from a consideration of the component frequencies resulting from the modulation of the gating function by the incoming information. Briefly, the theorem states that a signal of bandwidth B cps may be completely specified by taking and presenting amplitude samples at a rate not less than $2B$ samples per second. In the techniques of pulse-code modulation, samples so taken may be passed through a filter having a bandwidth B, and the original signal multiplied by an arbitrary constant will appear. In a color television display so time-divided the filter characteristic is supplied by the resolution capabilities of the viewer's eye.

This application of the sampling theorem specifies that the rate of presentation of information in a given color channel should be not less than three megacycles per second. The same arguments may be applied to the wide-band component of information which is common to all channels. Since this information is sampled every time a color sample is taken, it is presented at a rate which is the sum of the rates for the individual color gates. For reasons of switching economy, in our application of color switching the Chromatron, four samples of color information (with one repeated) constitute a sampling cycle. Thus the effective sampling rate for brightness information will be four times that allotted to the chrominance information.

A second consideration is the visibility of individual dots in saturated areas of a single color. In order to prevent the dots from being visible, their separation must be less than the angular resolution capability of the eye of a viewer at normal viewing distance. Experience has shown that this condition is satisfied if the number of bright dots per line is around 350, corresponding to something in excess of a 6-megacycle switching rate. One may take advantage of the principle of dot inter-

lace to decrease the effective dot spacing by suitably relating the scanning frequency and the switching frequency. If we choose the switching frequency to be an odd multiple of one half the line rate, dots of any given color will have appeared alternately in two positions on each line at the end of two frames. This gives the visual effect of having twice the dot rate. Since the areas involved are extremely small, flicker does not result from this technique.

The most conveniently available frequency in an NTSC signal having the desired properties is the color subcarrier frequency. In any compatible color receiver this frequency must be generated to perform the decoding function. We have chosen to utilize it for the switching function.

Color Switching Circuit

In order that each color be presented at a rate of at least 3.58 megacycles per second it is necessary to develop a potential changing at such a rate between the color grid terminals. Since the capacitance between the color control grids of present tubes is 1,400 micromicrofarads, the simplest way to do this is to resonate the capacitance at the desired frequency. An inductance of about 1.5 microhenries, connected in parallel, gives a resonant circuit across which a sinusoidal switching voltage may be developed with a minimum expenditure of power. With sinusoidal switching, the colors are presented in the sequence green, red, green, blue, for each cycle of switching voltage. The beam path during a part of one picture line will be as shown in Fig. 2. The solid curve shows a traversal for an odd numbered line, the dotted for an even numbered line. Due to the half-harmonic relationship between switching and horizontal scanning frequencies, the total number of red and blue dots appearing on a given line after two traversals is doubled. There is no interlacing of the green dots, because two green dots are produced in each cycle of the switching frequency, corresponding to 7.2 megacycle resolution without interlace.

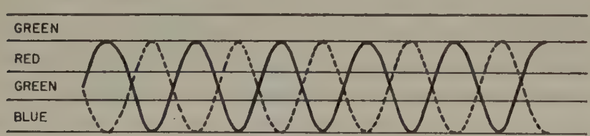

Fig. 2—Path of electron beam with sinusoidal switching, showing dot-interlace. Line 1, solid curve. Line 526, dotted curve.

The relative amount of time spent in each color may be controlled by the amplitude of the switching voltage. With the present experimental tubes, 325 volts rms is required to make these times equal. The power requirement depends upon the resonant impedance of the switching circuit. Since the switching voltage carries no modulation, we may keep the power small by the use of high Q circuits. The power loss in the grid itself is negligible when compared with the loss encountered in practical inductors (see Appendix). It has been possible to realize a Q of 200 for the circuit, giving a driving power requirement of 20 watts.

The design of an amplifier to supply this power is very simple. A beam tetrode is chosen to obtain high power sensitivity and eliminate the need for neutralization. Since the purpose of this stage must be to deliver maximum voltage across a load instead of maximum power output, no attempt is made to match impedances. Instead, the tube is operated in such a way as to minimize source impedance. In this manner, plate efficiencies up to 80 per cent may be realized.

Several advantages result from the use of a coaxial tank coil in the color-grid resonant circuit. Since it is important to keep the average potential of the two color grids equal, they should be driven from a balance circuit. The center-tap of the outer conductor of the coaxial coil can be connected to the shell at rf ground, satisfying this requirement, while one end of the inner conductor is grounded. The plate of the amplifier tube, connected to the other end of the inner conductor, supplies power at a level of voltage and impedance which permits higher efficiency than would be obtained from two tubes in push-pull driving the balanced color grid system. Sufficient insulation can be included between the inner and outer conductors to provide the dc isolation required when the shell and color grids are operated several kilovolts above the plate potential of the amplifier tube.

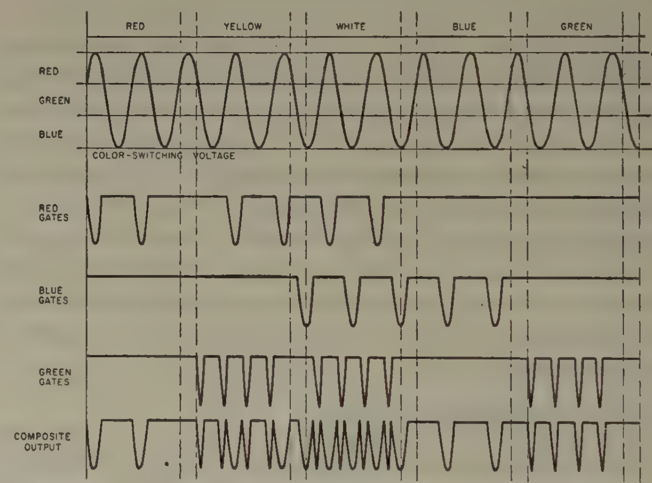

Fig. 3—Reproduction of color bars by the pulsed color voltage system.

Gating Circuits

Given a color tube and switching circuit as described above, it is necessary to control the instantaneous amplitude of the electron beam so that the correct amount of light will be reproduced in each of the three primary colors. This may be done by generating three pulsed video signals, whose amplitude corresponds to the light output desired in each color. The phase and frequency of these individual pulse trains is such that their maxima occur at the instant the beam is centered on the strip of corresponding color. (Suitable allowance must be made for transit time of electron from gun grid to color control grid.) These pulses are then added to form a composite pulsed video signal, and impressed on the gun control electrodes. Fig. 3 illustrates the way in which bands of various colors are reproduced in this scheme.

One gating circuit which we have successfully used is illustrated in the schematic diagram of Fig. 4. A beam tetrode (6CD6) was chosen for early experimental work with this circuit because it is capable of high peak plate current at low plate voltage. Subsequent work has shown that the requirements can be met with small tubes, such as the 6BQ6 and the 6CL6. In operation, a sine wave of the "appearance" frequency for a particular color, superimposed on a negative bias, is applied to the screen grid of the tube. By a suitable choice of the phase and amplitude of the screen signal, the pulses of plate current can be made to coincide with the electron beam incidence on a particular phosphor. The amplitude of the plate current pulses is controlled by the video voltage supplied to the control grid of the gate tube. Identical circuits are used in all three channels. The phases of the red and blue gate radio-frequency screen voltages differ by 180 degrees. The green channel must be pulsed twice during each cycle of color switching, since green is crossed twice. This is accomplished by driving the green gate screen with twice switching frequency, provided by conventional frequency doubling techniques. In order to avoid possible variations in the phase of the gate signals with respect to the switching voltage, a small signal is derived directly from the color grid circuit to drive a buffer stage. The balanced output of the buffer is used to drive the red and blue screen grids. One phase of the buffer circuit output also drives the frequency doubler, which automatically insures the correct phase relationship between the double and single frequency pulse trains.

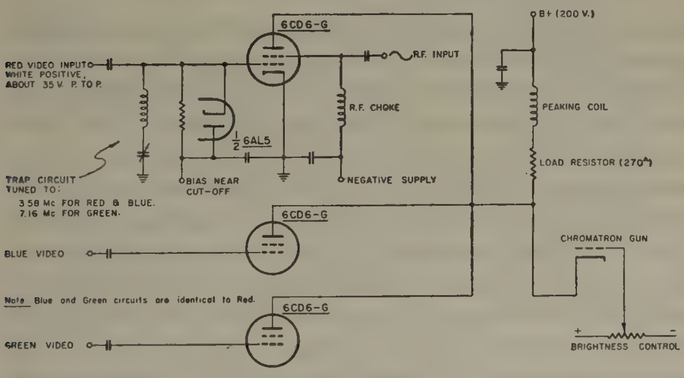

Fig. 4—Diagram of gating circuit.

The gate circuit must be capable of delivering an output signal of some fifty to seventy volts to utilize the full dynamic range of the Chromatron gun. Since the pulsed nature of the output requires a wide-band low impedance output circuit, the gain of this stage is small. In order to provide the required control range without drawing grid current, it is desirable to operate the tubes at cutoff with no signal input. By resorting to clamping in the control grid circuit and direct coupling the output signal to the color tube gun, this is possible. Since this circuit delivers negative output pulses for increasing light required, its output is connected to the electron gun cathode.

Laboratory Tests

In order to provide a practical demonstration of this arrangement, the circuits shown in the block diagram of Fig. 5 were set up. A standard DuMont color slide scanner was used to provide a three-color simultaneous signal. The synchronizing circuits of the scanner were modified so as to be controlled, as in an NTSC signal, by a 3.58-megacycle oscillator. The same oscillator signal was used to drive the color switching amplifier. The three-color video information from the scanner was amplified and delivered to the inputs of the three gate circuits described.

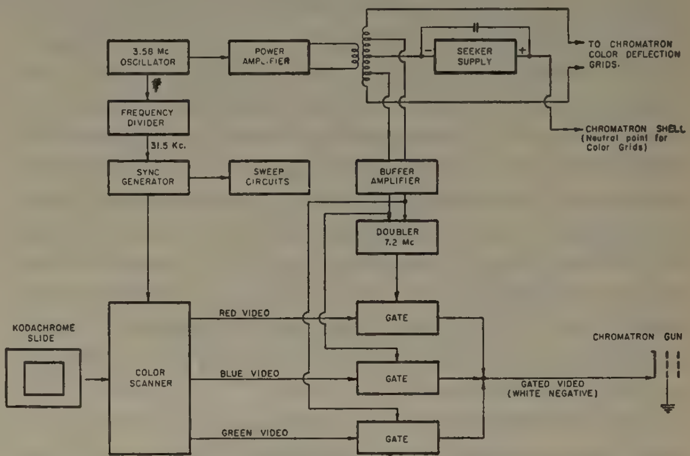

Fig. 5—Block diagram of experimental set-up to demonstrate the application of simultaneous signals to a single-gun color tube.

Color pictures of excellent quality were reproduced from both the standard NTSC test slide series and test patterns of various sorts. The horizontal and vertical resolutions were measured by standard techniques. They were found to be in excess of 270 lines horizontal, and 250 vertical, in a Chromatron with phosphor strips 0.015 inch wide. (Tubes capable of higher resolution are currently in the laboratory.) The brightness of full white areas was over 40 foot lamberts with 18 kilovolts total color tube accelerating voltage. This arrangement also demonstrated fully the advantages of using dot interlace in a rapidly switched display.

Operation with Color-Difference Signals

In all that we have said so far there has been no need to bring differences of phosphor efficiency into the discussion. As is well known, the three phosphors used in color tubes do not in general give equal radiant energies for equal electron current. In the case where signals giving the required light in each primary color are being impressed on the gate circuits, it is necessary only to adjust the gain of each channel to compensate for differences in phosphor efficiency. In order to assure that a tinted grey scale will not result from this procedure, it is necessary the gate circuits be quite linear, or that any curvature of their characteristics shall match, even though they operate over different ranges of output.

There would be appreciable savings in the circuits required in a receiver for the NTSC signal if information

of the form $E_b - E_y$, $E_g - E_y$, and $E_r - E_y$ and the brightness signal E_y could be added in the grid-cathode circuit of the electron gun or guns of the color tube. In general, with three gun tubes, this procedure proves unsatisfactory. This is due principally to two effects. The first of these has to do with the problem of providing three guns whose characteristics will match. This is difficult, since electron guns must operate at very high current densities. In order to provide the current densities required, extremely small grid-to-cathode and grid 1-to-grid 2 spacings are involved. Small variations in these spacings make large changes in the beam currents produced for given electrode potentials. This effect is well known in ordinary black-and-white tube production. There it makes little difference, since the only adjustment required to correct for it in use is a change in the operating bias to assure cutoff when the signal is at black level and a corresponding change in the over-all signal level to restore the full dynamic range. With any multiple electron beam structure, one will seldom find equal cutoff voltage and transfer characteristics among the various guns. If one wishes to utilize the advantage of color-difference operation, it is essential that these characteristics be closely identical. Otherwise color contamination, or tinted grey scales in "monochrome" picture areas, will result.

Even if it were possible to assure identical characteristics among several guns throughout their useful life, the differences in luminous efficiency among the several phosphors will force one to operate the corresponding electron guns at different beam amplitudes, where white is produced. Due to the fact that each gun must handle quite different amounts of current they will have different transfer characteristics, and again the addition of the brightness signal to the color minus brightness signal will not take place in the same way for each color channel. This will again result in de-saturation and tinted grey scale effects.

With a single gun tube there is no problem of matching gun structures. The problem of differing phosphor efficiencies is still present, but the designer has at his disposal one more variable which can serve to obviate the difficulties and permit the gun to operate over exactly the same current range in reproducing the full dynamic range of any color. This variable is the time width of the electron pulses used to actuate the various phosphors. Making the total time which the electron beam spends in exciting each primary color inversely proportional to the relative efficiency of that phosphor, a balanced white output results at equal peak beam currents. If this technique is used, color-difference signals having exactly the same ratio to the brightness signal as existed in the originally encoded information may be delivered to the gate circuit. Those stages will then operate over identical dynamic ranges. The composite pulsed signal generated in the gates has an amplitude proportional to the color minus brightness information, and may be impressed on one of the gun control electrodes. The brightness signal may be impressed on the other control electrode, in the proper phase to give addition. A picture correct both as to grey scale and color balance at all brightness levels will result.

If signals of the form $E_c - E_y$ are to be used to control the amplitude of the gate circuits, it is no longer permissible to have the gates at cutoff bias and zero pulse output for no-signal conditions. This is because signals of that form may have both negative and positive values, and the output must therefore be able to fluctuate about a mean value corresponding to zero. The pulse diagram of Fig. 6 shows the biases and signals which would be delivered to the gun under conditions of no light, full white, half white, full blue, and 50 per cent

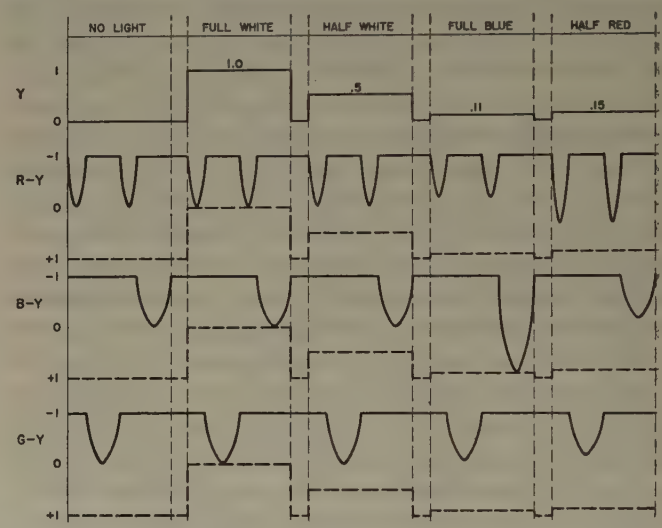

Fig. 6—Pulsed color-difference signals (double red tube). Note that the Y signal is drawn dotted under each color-difference signal to show the net grid-to-cathode voltage for each condition.

red output. For clarity it is assumed that the system gamma exponent and the corresponding electron-gun transfer characteristic is unity. It will be noted that in this diagram we have chosen red as the double color instead of green. The reason for this will appear in the discussions relating to the bandwidth requirement of the gate circuit. In setting up Fig. 6, we assume an arbitrary reference potential of zero. The cathode of the electron gun is biased to the positive voltage required to cut off the electron stream with respect to this arbitrary zero. The gate circuit must supply pulses which under quiescent conditions, are equal in amplitude to the cutoff voltage of the electron gun. The control grid of the gun is biased negatively, with respect to our arbitrary zero, by another voltage equal to cutoff. The E_y signal is applied to the gun control grid. Under quiescent black conditions, we have E_b, E_g, E_r and $E_y = 0$. Since at no time does the instantaneous potential between the grid and cathode equal less than cutoff, no light will result. If we desire to make full white ($E_y = E_b = E_r = E_g = 1$ in units of cutoff), the color-difference signals are again equal to zero, but the brightness signal will reduce the control grid potential to zero, and the proper current will flow in each successive pulse to cause the phosphors to produce equal radiant energy. The remaining three diagrams show the conditions which exist for various amounts of saturated primary colors.

The maximum pulse amplitude which the gate circuits are ever required to produce occurs in the case of a saturated blue area. This amplitude will be the voltage required to cut off the electron beam times 1.89.

Bandwidth Requirements

The load impedance which must be used for the gate circuits is determined primarily by the bandwidth which must be allotted to the pulsed signals used to drive the gun cathode. Since we must develop a given voltage across this load, it is desirable to keep the impedance of the load as high as possible and hence the bandwidth to a minimum value. The bandwidth must be consistent with adequate pulse performance to assure freedom from overlapping of pulses and consequent color contamination. The bandwidth needed is inversely proportional to the time width of the shortest pulse to be reproduced. If we simply let the beam spend equal time in all colors, the shortest pulse will be the one corresponding to the color which is excited twice in the color switching cycle. The pulse width for the shortest pulse will then be 60 degrees of one switching cycle. To reproduce such a pulse with sufficient accuracy to prevent appreciable color contamination requires a bandwidth in the pulse circuit exceeding 14 megacycles. This bandwidth is within the limits of practical technique, since it need not appear in stages required to have high voltage gains. It would be undesirable to have to go much beyond this.

If we are to utilize various pulse widths to correct for phosphor efficiencies, we are therefore constrained to putting the most inefficient phosphor, red, in the position where we can use the inherently short double switching frequency pulses to excite it. We may then reduce the width of the switching frequency pulses, used to excite the more efficient phosphors, down to the width of the double frequency pulses, without requiring increase in the 14-mc bandwidth of the output circuit. For equal peak beam current, this would correspond to a fifty per cent reduction in the total electron current delivered to the more active phosphors, relative to that delivered to the red phosphor, in each switching cycle. If the efficiency of the green and blue phosphors is not larger than twice the red, we may therefore use the technique of pulse width control for balancing, without increasing the bandwidth of the pulse circuit.

Fortunately, it is possible to choose phosphors which satisfy this criterion. In practice it has proven possible to make the relative efficiency of the blue phosphor approximately equal to that of the green. Each of these has an efficiency relative to that of red of approximately 2. Small variations in tube manufacturing tolerances may be allowed by making the conduction time of the gate circuits adjustable. The adjustment procedure is exceedingly simple. One merely sets the grid bias of the electron gun to a point where light is being produced at the viewing surface, and then sets three gate screen and rf voltage bias adjustments to give a balanced white. The application of this pulse-width-control technique is not limited to the case where color-difference signals are being used to operate the single gun display. It is equally applicable to the case where we first derive signals of the form E_r, E_b, E_g for application to the gate circuits of Fig. 4. Although the advantages of receiver simplification are no longer obtained, its use permits these gate stages to operate over identical ranges of input signal, and hence one will have closely matching transfer characteristics.

To demonstrate the practicability of displaying color-difference signals in this way the circuits in the block diagram of Fig. 7 were constructed and tested. The three-color video output of the scanner was connected to a matrix and filter network, serving to generate an artificial set of color minus brightness and brightness signals.

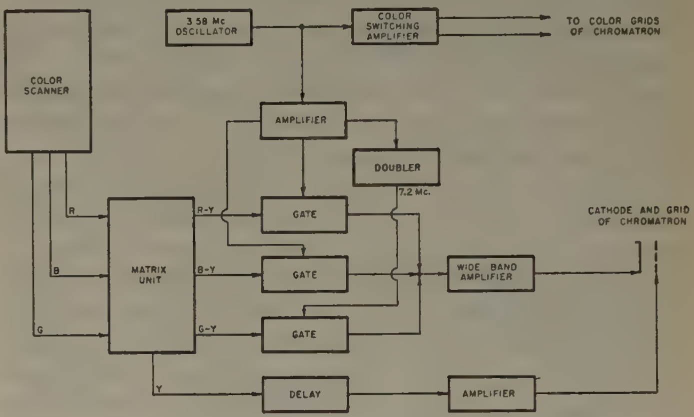

Fig. 7—Block diagram of color-difference demonstration with low-level gating.

The matrix unit was arranged to give these signals with the bandwidths and relative amplitudes which they would have, had they come from a receiver and decoder operating on a signal having the NTSC specifications. Because of the necessity for larger pulse amplitudes and a steady pulse output at zero signal, the gating was done at a lower signal level, then required to drive the cathode of the color tube. This low-level gating circuit was followed by a pulse amplifier having a gain of about three. By this means the capacitance seen at the output of the pulse amplifier was kept low compared with that of the paralleled gate circuits. The brightness signal was amplified through an ordinary video amplifier and delivered to the control grid of the electron gun.

Demonstrations proved the technique to be capable of producing a tricolor picture of excellent definition and tonal quality.

Presentation of Monochrome Pictures

With either of the techniques described, monochrome display has proven to be no problem. If the technique of pulse width control is used to balance the phosphor output, an equal monochrome signal delivered to the three-gate inputs for the first method, will result in a balanced monochrome display. In the second case, the gate inputs are left at zero, and the monochrome signal is impressed on the gun control grid just as in ordinary black-and-white practice. In either case, receiver circuits may be arranged such that this condition will auto-

matically result upon the disappearance of the chrominance signal. It should be emphasized that the method produces a grey scale having properly balanced colors at all light levels, since identical transfer characteristics are involved at all times.

Radiation of Switching Signal

One problem which faces the designer of terminal equipment using this system is that of adequate radiation suppression at the subcarrier frequency. Higher levels of the subcarrier must be generated to perform the switching function than are normally required for decoding. This high level signal has very low harmonic content and is confined to only one resonant circuit, which must be adequately shielded. The color grid itself produces negligible radiation, since it is made up of hundreds of wires, each carrying equal current in opposite directions. The spacing between these individual current elements is of the order of 10^{-5} wavelengths at switching frequency. Therefore the direct radiation from this source will be unimportant. Care has been taken in the design of the color grid support frames, to assure that the radio-frequency currents will be balanced by nearby currents of opposite direction to minimize radiation. The magnetic field of the inductance used to resonate the grids can be contained by ordinary shielding techniques. For the rest of the apparatus, the signal levels are of essentially the same range as encountered in other comparable color television circuits, and may be dealt with accordingly.

In connection with this problem it should be noted that the magnitudes of the wavelengths are vastly different than those encountered in vhf local oscillator radiation problems. The local oscillator signals must appear in circuits more or less intimately associated with the antenna. Furthermore, their wavelengths are such that physically small structures may be efficient radiators. The subcarrier frequency however has a wavelength of 84 meters. Clearly no components having dimensions comparable to a wavelength are at all capable of fitting into a television receiver. Since the subcarrier frequency is very well defined, highly efficient rejection filters of simple design may be incorporated into such auxiliary circuits as antenna and power line connections.

Conclusions

It is our feeling that the techniques of color television picture reproduction, described above, offer several important advantages, both in manufacture of the color tube and in the design of receivers for its use. When compared with multiple beam reproduction methods currently available, some advantages are:

1. Simplified scanning components and circuits.
2. No problems of raster registration.
3. Direct tube interchangeability, requiring only non-interacting adjustments of biases and signal levels.
4. Excellent black-and-white reproduction without change of hue with brightness level.
5. Large area, bright pictures.

The color tube itself is a comparatively simple device, and the use of color-control and beam focusing at the viewing surface permits the use of large scanning angles which results in a short over-all length.

As of the present writing, one could design a practical operating receiver for the NTSC system of color television in the ways outlined, having few if any more tubes than required by other existing methods. The power requirements for the switching and gating circuits combined is less than that used in the scanning of a large area monochrome display. It should be emphasized that the circuits described in this paper were intended only for purposes of demonstrating the validity of the ideas involved. They were not intended as designs for production receivers. Many simplifications will occur to the reader, as they have to the authors. However our accent was on laboratory convenience and not the elimination of components.

The demonstration equipment described in this paper has been viewed by many persons, both in and outside the television industry. We feel that the general satisfaction expressed by those who have seen color pictures produced by this technique represents, in itself, solid proof of the practicability of the method. As will have been seen, there are no problems beyond the capabilities of current engineering practice in using this method.

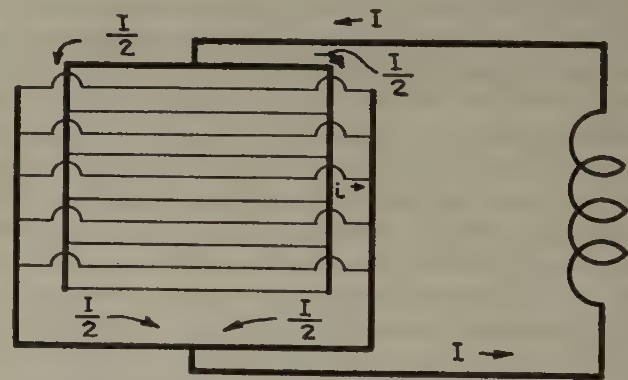

Fig. 8—Diagram of resonant circuit including color structure.

Appendix I

Calculation of power dissipation in the color grids of a Chromatron. The color grid is a capacitor consisting of two sets of lossy wires, each wire being connected at each end to a frame (Fig. 8).

l = length of wire
i = current at end of each wire
ρ = resistance per unit length
x = distance from middle of wire to an element
I = line current
N = number of wires

$$i = \frac{I/2}{N/2} = \frac{I}{N}.$$

Power dissipated in element dx

$$P_1 = \rho\left(\frac{ix}{1/2}\right)^2$$

$$P_1 = 4\rho\frac{i^2x^2}{l^2} = \frac{4\rho I^2x^2}{N^2l^2}.$$

Power dissipated per half wire

$$P_2 = \frac{4\rho I^2}{N^2l^2}\int_0^{l/2} x^2dx$$

$$P_2 = \frac{\rho I^2 l}{6N^2}.$$

Total power dissipation in the grid

$$P_T = 2NP_2 = \frac{\rho I^2 l}{3N}$$

ρ (measured) = 1.28 ohms/inch
I = 10 amperes
N = 400 wires
l = 14.5 inches
P_T = 1.5 watts.

Improvements in the RCA Three-Beam Shadow-Mask Color Kinescope*

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***Summary*—This paper describes the advances made by RCA in the development of a production design for an all glass shadow-mask color kinescope. The constructional features of the early RCA shadow-mask color kinescope are reviewed briefly, and recent improvements in tube construction are described. These improvements contribute both to improved tube performance and to a simplification of fabrication and assembly operations. Specific constructional and processing advances are discussed.**

Introduction

At the several demonstrations given by RCA during 1950 and 1951, both publicly and as part of the hearings before the FCC, it was clearly indicated that the basic principles of a single tube for the reproduction of color pictures had been developed. The principles of operation of this tube, later to be known as the RCA shadow-mask tricolor kinescope, together with its constructional details and manufacturing techniques, were described in a series of papers published in October, 1951.[1–5]

Although the tube at that time could not be considered a finished production design, the problems still to be solved were generally of a nature capable of solution by those skilled in the fabrication of black-and-white kinescopes. Accordingly, a program was initiated at RCA to develop a tube design suitable for mass production. This paper will review the major accomplishments of that program.

Description of "Old-Design" Kinescope

In order to appreciate what improvements have been made, it is necessary to review briefly the design previously described, which is now referred to as the "old design." Fig. 1 is a cross-sectional diagram of the "old design" three-beam shadow-mask tricolor kinescope showing the major tube parts and their relative positions. From left to right, the diagram shows the base, the gun assembly, the neck, and the glass funnel sealed to the outer metal shell. A magnetic shield of high-permeability metal is provided inside the shell to reduce the effects which any external magnetic fields might have on the electron beams. The shadow mask and phosphor-dot plate are located just forward of the

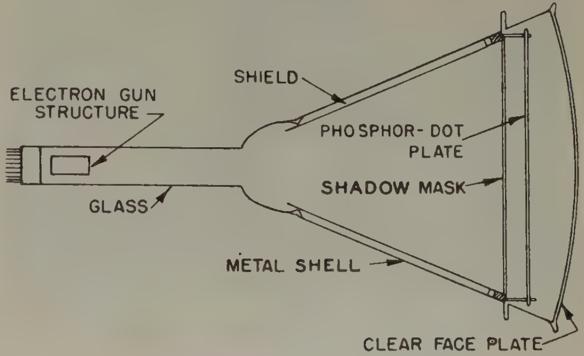

Fig. 1—Cross-sectional diagram of tricolor kinescope.

* Decimal classification: R583.6×535.6. Original manuscript received by the Institute, October 16, 1953.
† Reese Padlock Co., Lancaster, Pa.
‡ Tube Department, Radio Corporation of America, Lancaster, Pa.

1 H. B. Law, "A three-gun shadow-mask color kinescope," Proc. I.R.E., vol. 39, pp. 1186–1194; October, 1951.
2 N. S. Freedman and K. M. McLaughlin, "Phosphor-screen application in color kinescopes," Proc. I.R.E., vol. 39, pp. 1230–1236; October, 1951.
3 H. C. Moodey and D. D. VanOrmer, "Three-beam guns for color kinescopes," Proc. I.R.E., vol. 39, pp. 1236–1240; October, 1951.
4 B. E. Barner and R. D. Faulkner, "Mechanical design of aperture-mask tri-color kinescope," Proc. I.R.E., vol. 39, pp. 1241–1245; October, 1951.
5 D. D. VanOrmer and D. C. Ballard, "Effects of screen tolerances on operating characteristics of aperture-mask tri-color kinescopes," Proc. I.R.E., vol. 39, pp. 1245–1249; October, 1951.

welding flange and as close to the face of the tube envelope as is practical. In order to obtain precise alignment between the apertures in the mask and the phosphor dots, it is necessary that the mask and phosphor-dot plate be mounted together in an assembly. This assembly is then placed in the envelope and held in proper relationship to the gun. Fig. 2 shows front and rear views of the viewing-screen assembly.[4]

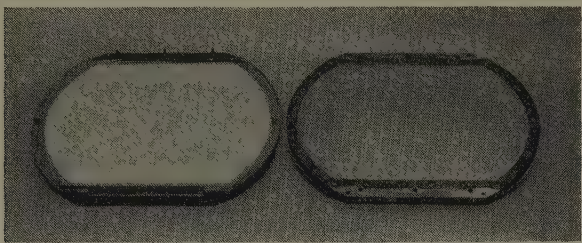

Fig. 2—Front and rear view of viewing-screen assembly.

Fig. 3 is a picture of the gun assembly. Three parallel, closely spaced, electron guns—built into a unit—provide separate beams for excitation of the three different phosphor arrays. Each of the three guns includes an indirectly heated cathode and four grids. The No. 4

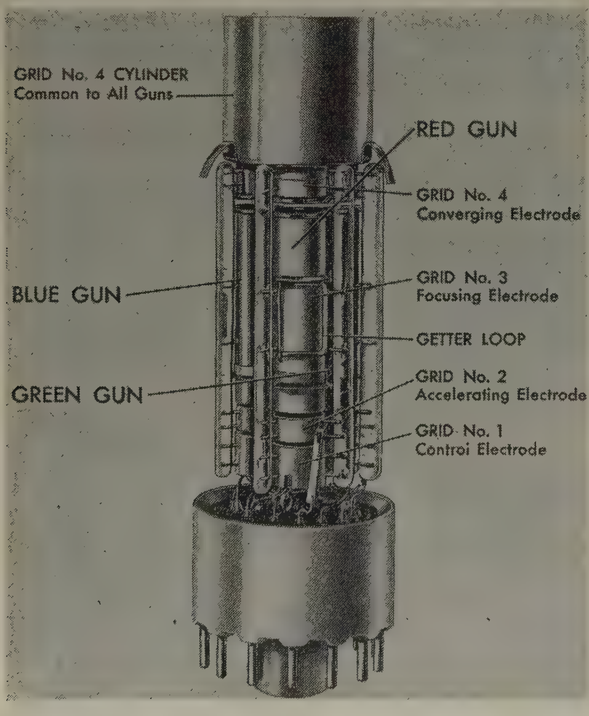

Fig. 3—Structure of three-gun assembly.

grids of the three guns open into a common cup to which they are connected. This cup can be seen at the top of the mount. When the tube is in operation, a field exists between this cup and the conductive neck coating to provide an electrostatic lens which serves to converge the three beams at the shadow mask.[3] Separate leads are brought out through the base from the three cathodes, the three No. 1 grids, and the three No. 2 grids, to permit adjustment of individual drive characteristics. Thus it is possible to control the brightness of each of the three colors independently.

The envelope used for the "old design" tubes was a 16AP4 metal shell modified so that the viewing-screen assembly could be mounted near the faceplate. The shell assembly actually consisted of two pieces, an upper and lower section. These two sections were heliarc-welded together after the viewing-screen assembly and magnetic shield had been fastened in the lower section.[4] This envelope accommodated a viewing-screen assembly providing a picture $11\frac{1}{2}$ inches by $8\frac{5}{8}$ inches with rounded ends. Fig. 4 shows the completed tube.

Fig. 4—Three-gun tricolor kinescope, old design.

Objectives of Improvement Program

The development of a color kinescope more suitable for mass production has centered around three basic objectives:

1. Improvements in tube performance.
2. Interchangeability of parts.
3. Decrease in tube cost.

The second objective refers to the development of techniques whereby the various parts of any viewing-screen unit may be interchanged with the parts of any other viewing-screen unit.

The third objective is aimed at the pricing of a color television receiver for the mass market. These three objectives—improvement in performance, interchangeability, and decrease in costs—are interrelated.

Improved Performance

One of the first improvements in performance resulted from the development of an improved blue phosphor. The blue phosphor used in the early tricolor kinescopes had a relatively longer decay characteristic than the corresponding red and green phosphors. This longer decay characteristic resulted in so-called "trailing," which gave a slight bluish color to the "trailing" edge of objects in motion, as well as a general bluish overcast. The remedy for these defects was the development of a new material for the blue-emitting phosphor which provided a much better balance with

the red-emitting and green-emitting phosphors. The new phosphor was silver-activated zinc sulfide containing a sufficient amount of magnesium oxide to balance its efficiency with that of the green phosphor. Curves of the spectral-energy emission characteristics of phosphors currently used are shown in Fig. 5.

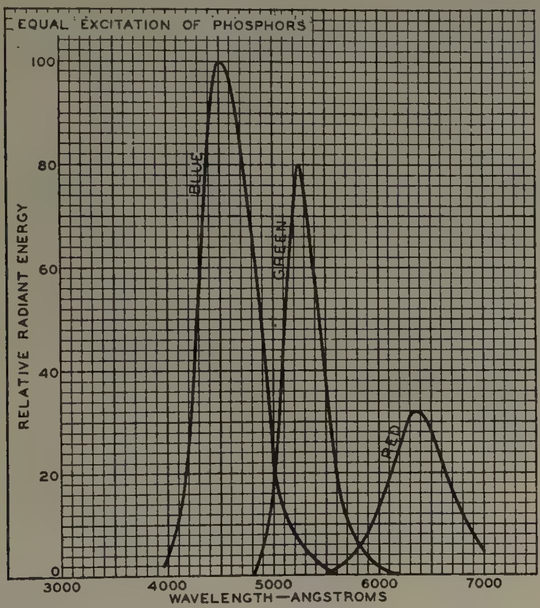

Fig. 5—Spectral-energy emission characteristics of phosphors.

Fig. 6 is a comparison between the range of the color primaries for the tricolor kinescope and the color primaries of modern printing inks. It is evident that the phosphor primaries have a range superior to that of printing inks and are sufficiently close to the values suggested by Hardy and Wurzburg for excellent color reproduction.[6] The values suggested by Hardy and Wurzburg are shown as three crossed circles on the locus of the CIE curve.

Improvements in screen-making techniques and in construction of the viewing-screen assembly, which will be described in more detail later, have resulted in greatly increased purity of the color fields, permitting excellent color rendition for color television as well as reproduction of good black-and-white pictures.

The convergence of the three beams at the viewing-screen assembly has been improved by better jigging of the gun parts during assembly of the gun and by a redesign of the deflecting yoke to provide a more nearly optimum flux pattern within the yoke. Beam convergence in the new tube is now considered commercially satisfactory.

The light output of the tube has been increased by improvements in the method of application of the phosphors and by improved screen processing schedules which result in higher phosphor efficiency. The beam energy to the phosphors is limited by the amount of beam energy which the shadow mask can dissipate before it reaches a temperature at which differential expansion between the mask and frame causes the apertures and dot trios to become misregistered. By development of an improved method of processing the mask, as well as improvement in mask material, the beam energy which may be dissipated by the mask has been increased by a factor of $2\frac{1}{2}$. This increase in the dissipation capacity of the mask proportionately increases the permissible beam energy to the phosphors and results in increased light output.

Improvement in contrast ratio has been obtained by two major modifications. First, a neutral filter glass (also often referred to as "grey" or "black" glass) has been substituted for the clear glass phosphor-dot plate. Second, improved techniques for aluminizing the phosphor-dot plate have been developed to provide a more uniform aluminum coating of the exact thickness required for best balance between contrast improvement and light output.

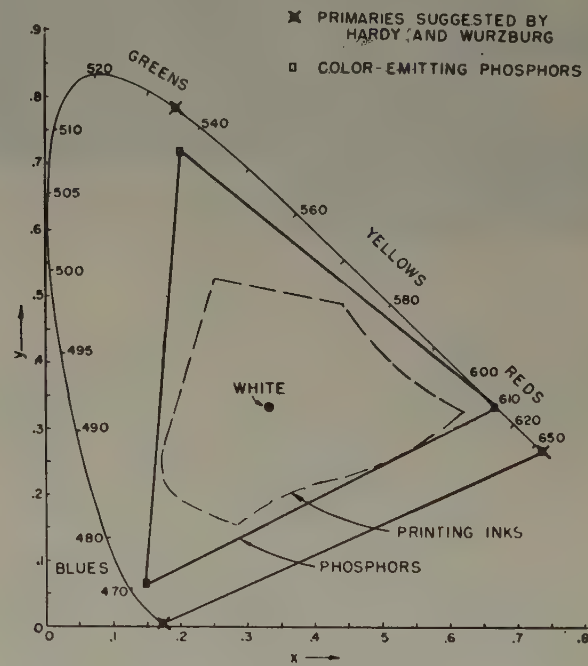

Fig. 6—CIE chromaticity diagram.

A balance has been achieved between the factors controlling contrast ratio and those controlling light output, so that the tube now produces a picture having a contrast ratio equal to that of black-and-white tubes of comparable size and a high-light brightness capability of 30 to 40 foot-lamberts. The light output is considerably greater than that of the tubes shown at the first demonstrations in 1950 and 1951.

"Old-Design" Viewing-Screen Assembly

Fig. 7 shows the parts used in the viewing-screen assembly for the "old-design" tricolor kinescopes, including those displayed and sampled to the industry through most of 1952. The major parts are the shadow mask, spacer frame, and phosphor-dot plate. Also shown are the necessary auxiliary parts: the mask-clamping

[6] A. C. Hardy and F. L. Wurzburg, Jr., "The theory of three color reproduction," *Jour. Opt. Soc. Amer.*, vol. 27, pp. 227–240; July, 1937.

segments, alignment pins, glass clamps, and screws. The basic parts of this assembly required extremely precise and, consequently, costly fabrication. The spacer frame between the mask and the phosphor-dot plate had to be machined in thickness to an accuracy within ±0.001 inch. The alignment hole and slot on opposite sides of the spacer frame were located by a drill jig and then drilled and milled to a tolerance of 0.0005 inch. The holes in the glass phosphor plate were drilled under water with an undersized diamond drill, and then reamed to size to a plus tolerance of 0.0005 inch in hole diameter.[4]

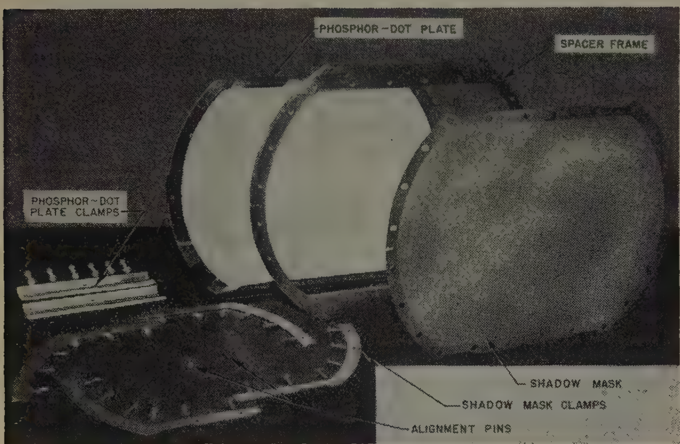

Fig. 7—Exploded view of viewing-screen assembly, old design.

In the "old-design" tubes, each viewing-screen assembly had to be treated as an individual unit. A gelatin screen stencil had to be prepared for each shadow-mask-frame assembly, and the phosphor-dot plate screened from this stencil had to be properly identified so that it could be assembled later with the proper shadow-mask assembly.[2] Registration between the apertures and phosphor-dot trios on the glass plate was obtained by photographic transfer of the location of the alignment slot and hole in the frame to a gelatin stencil, and accurate alignment of the reamed holes in the glass plate with the hole and slot in the stencil by the use of a microscope as a visual aid. This procedure required considerable skill on the part of the operators at each stage of the processing. The production problems associated with this design were difficult and the costs prohibitively high because the phosphor-dot plate and shadow-mask-frame assemblies were not interchangeable.

Interchangeability of New Design

The new viewing-screen assembly, which overcomes most of the objectionable features of the old, has means for adjusting the spacing between the phosphor-dot plate and shadow mask. With this assembly it is no longer necessary to treat each shadow-mask-frame assembly as an individual unit. As a result, the need for making a gelatin screen stencil for each assembly has been eliminated and it is possible to print a number of phosphor-dot plates from a single gelatin stencil. In fact, an etched metal screening stencil may be substituted for the less durable gelatin, or any one of a number of printing techniques may be used.

The interchangeability between mask-frame assemblies and phosphor-dot plates is based on the principle that homogeneous metals expand uniformly when uniformly heated. How interchangeability can be obtained through this principle can best be explained by reference to the diagrams in Figs. 8 and 9. Fig. 8 represents a

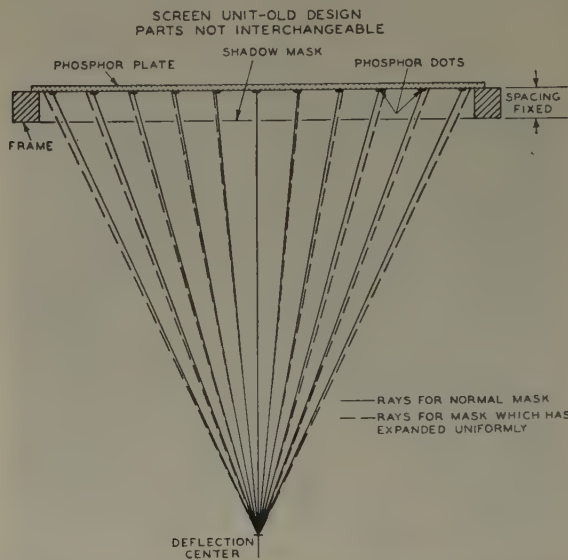

Fig. 8—Diagram showing noninterchangeability of old design.

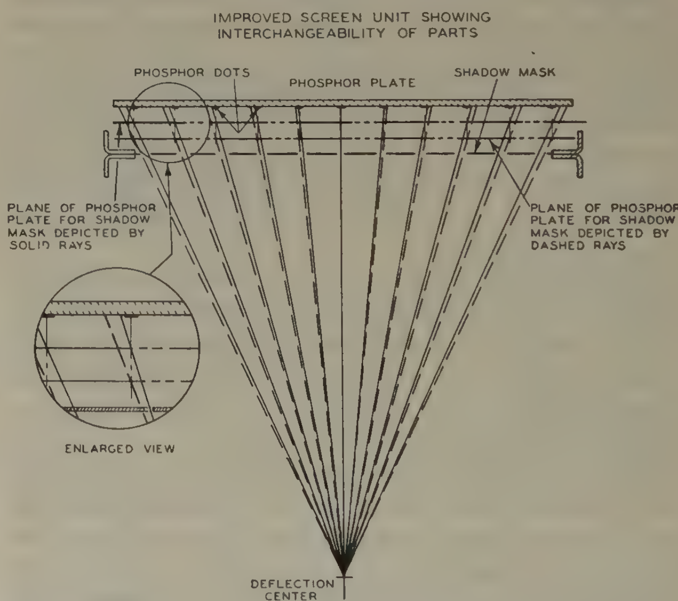

Fig. 9—Diagram showing interchangeability in new design.

viewing-screen assembly of early design, in which the separation between the phosphor-dot plate and shadow-mask is fixed by the thickness of the frame. The solid rays represent the condition which exists when the apertures and phosphor-dot trios are in exact registry. If another identical shadow-mask is "hot-blocked" to an identical frame, but at a slightly higher "hot-blocking" temperature, then the mask will expand uni-

formly to a greater degree, thereby changing the position of the apertures to those shown by the dashed rays. It is evident that the phosphor-dot trios are no longer aligned with the apertures. Fig. 9 is a diagram of the new viewing-screen assembly. The same two conditions are shown by the solid and dashed rays. It is evident that perfect alignment between the apertures and phosphor-dot trios can be obtained by adjustment of the spacing between the phosphor-dot plate and shadow mask, provided the shadow-mask dimensional changes are uniform. These expansion requirements can be obtained readily in practice.

Temperature control of the metal and photographic plates during the photoengraving process used in making the shadow masks is not necessary because it may be assumed that any temperature change will effect the expansion of the metal or photographic plates uniformly and, hence, the dimensions of the array in a like manner. Thus, the absolute dimensions of each shadow mask before "hot-blocking" need not be the same as those of every other mask provided any dimensional differences that do occur are uniform.

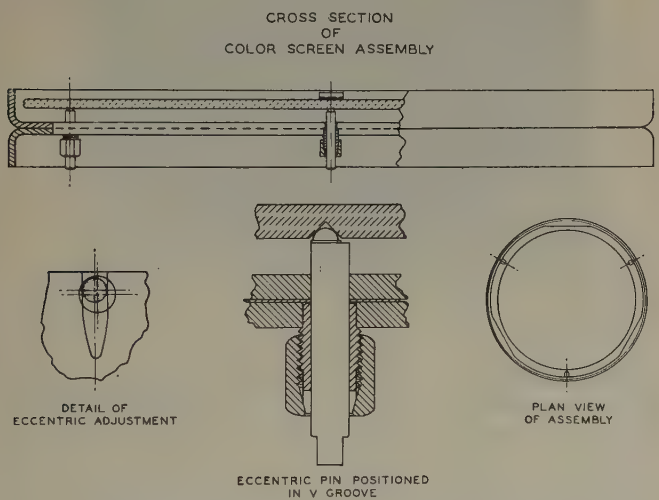

Fig. 10—Details of viewing-screen assembly.

A diagram of the new viewing-screen assembly illustrating the method used to obtain the adjustable spacing between the shadow mask and phosphor-dot plate is shown in Fig. 10. Three straight-sided pins which fit in collets equipped with locking nuts are located on the periphery of the frame 120 degrees apart. On the head of each pin is a hemisphere which is located off the axis of the pin as shown in the detail of the eccentric adjustment in Fig. 10. These heads mate with three V grooves in the glass plate, as shown. Provided the orientation is not altered, there is only one position in which the glass plate can fit upon the three hemispherically headed pins. The glass plate may be lifted off the pins and, when replaced, will always seat in exactly the same position. It is interesting to note that the dimensions of the heads of the pins and of the grooves are not critical in order to obtain perfect mating of the parts. Fig. 11 is a close-up view of the V groove, eccentric pin, and collet.

The separation or spacing between the shadow mask and phosphor-dot plate is adjusted by sliding the pin in the collet. The apertures and phosphor-dot trios are brought in horizontal alignment by rotation of the pins, which moves the plate to the desired position. The proper position of the eccentric pins is determined by placing the "hot-blocked" shadow-mask-frame assembly in a jig called an "alignment lighthouse," shown in Fig. 12. This jig holds the viewing-screen assembly in proper

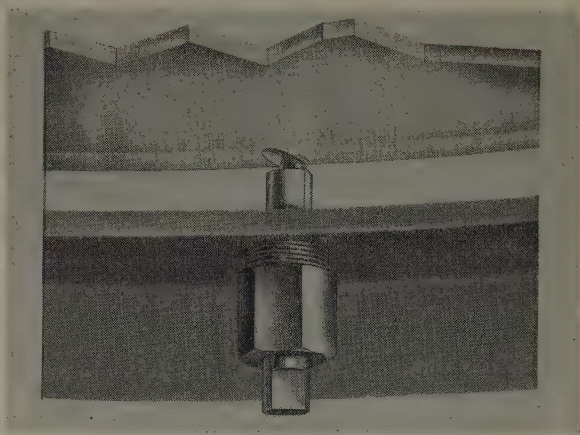

Fig. 11—Detail of phosphor-plate adjustment mechanism.

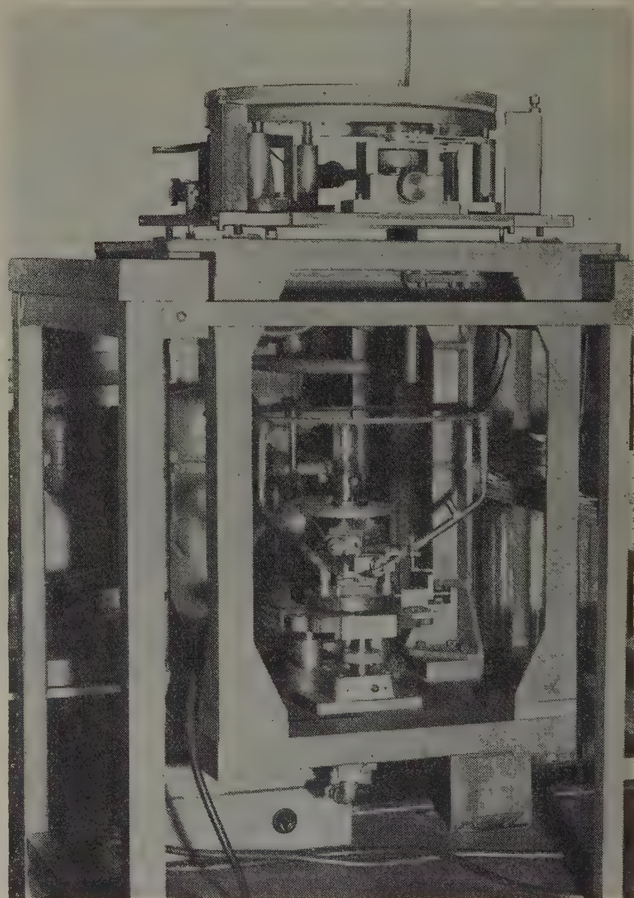

Fig. 12—Alignment lighthouse.

relation to a small light source located in a position corresponding to that of the electron beams as it passes through the deflection center in an actual tube. The "alignment lighthouse" is equipped with a mechanism for moving the eccentric pins and tightening the collet locking nuts. The proper position of the phosphor-dot plate relative to the shadow mask may be determined in two ways: by observation through a magnifying lens of the halo around the phosphor dots created by the light rays passing through the apertures, or by observation with the unaided eye of the diffraction patterns which appear around the light source.

This design of the viewing-screen assembly has another important feature. Misregistration between the apertures and phosphor-dot trios resulting from thermal expansion of the frame and glass phosphor plate is reduced to one-half the magnitude of the misregistration in the old assembly. The glass phosphor plate of the "old design" was registered with the frame by means of two pins. One pin fitted into a hole in the frame and the other rode in a slot. When the parts expanded during normal operation of the tube, all the movement occurred at the slot end of the assembly. The plan view of the improved assembly, shown in Fig. 10, shows that the center of the phosphor-dot plate is artificially fixed to the center of the mask by means of the radial arrangement of the V grooves. Expansion of the phosphor-dot plate is essentially uniform about this center and, therefore, the phosphor-dot trios at one edge of the plate move only one-half as much with respect to their apertures as they would if the plate expanded about a pin located at the opposite edge.

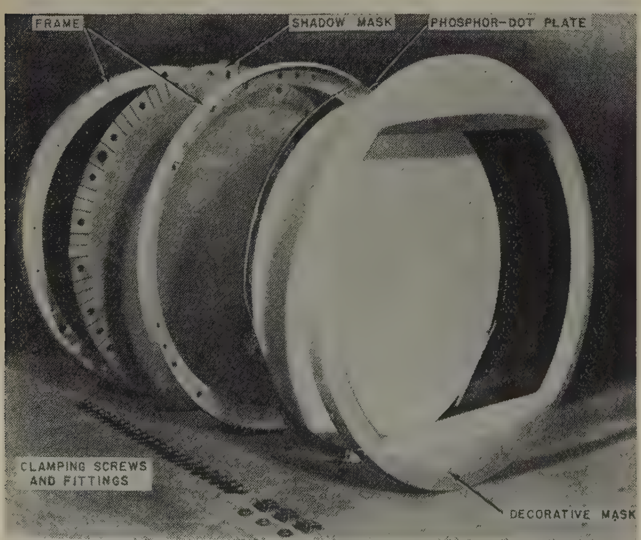

Fig. 13—Exploded view of new viewing-screen assembly.

The parts for the new viewing-screen assembly are shown in Fig. 13. The major parts are the phosphor-dot plate, the shadow mask, the frame, now in two parts, and the decorative mask. Also shown are the necessary auxiliary parts: the clamping screws, phosphor-dot plate clamps, and nuts. None of the parts require precision machining.

Shadow Mask

As in the "old design," the shadow-mask is made of cupro nickel (an alloy of 70 per cent copper, 30 per cent nickel) 0.002 to 0.004 inch thick. The material need only be as thick as can be conveniently handled in production in order to ease the chemical etching process and to lessen the load provided by the stressed shadow mask on the frame. Fig. 14 is a view of the improved shadow mask. In the border of the mask are three radially elongated holes, a number of narrow radial slots, two identification tabs, and twenty-seven holes.

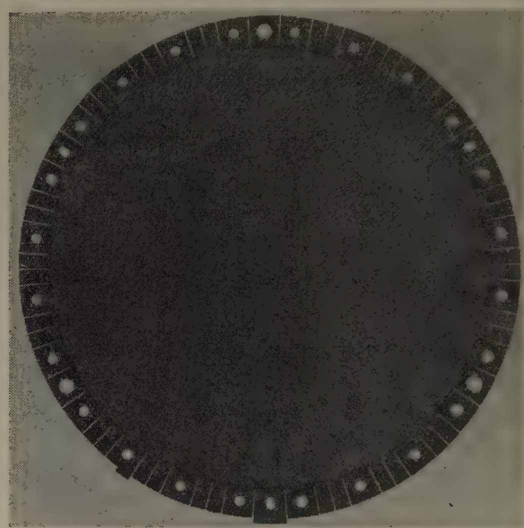

Fig. 14—Plan view of shadow-mask.

All holes and slots are chemically etched by mass-production photoengraving techniques, and the small apertures are held to a diameter tolerance of less than ± 0.0005 inch. The need for the unique arrangement of radial elongated holes, identification tabs, narrow radial slots, and holes in the border will be explained later.

The uniformity of the aperture size and spacing has been improved considerably since the early tubes were demonstrated by the use of a higher-quality master dot array and the development of improved melting and rolling processes to produce a more homogeneous alloy from which the mask is etched. These improvements have resulted in color fields which are more uniform and free from streaks and, therefore, provide better color rendition in the viewed picture. Uniform fields are of particular importance when black-and-white pictures are reproduced on the tricolor kinescopes.

The shadow masks are given a chemical treatment by a hot dichromating process to provide higher thermal-radiation properties. This treatment permits a greater electron-beam energy to be dissipated by the mask before the temperature reaches the point at which all the stress is relieved; a further increase in temperature beyond this point would cause the mask to buckle.

Frame

The frame, shown in Fig. 15, consists of two parts, the upper section and the lower section. These frame sections are drawn from $\frac{1}{8}$-inch hot-rolled steel sheet by conventional methods. The only critical requirement is that the land on the bottom of the frames be flat to within 0.005 inch of a plane. This flatness is readily achieved in practice with normal precautions. All the holes for the clamping screws and fittings are pierced at one time to commercial tolerances by conventional methods. The holes in the lower frame for the clamping screws are then tapped. The miscellaneous fittings are welded or furnace-brazed in position by the use of standard commercial techniques.

Fig. 15—Frame.

Originally, it was thought necessary to center load the frame to prevent it from warping. Hence, the frame was designed with two similar parts, the upper and lower sections, with the mask sandwiched between these two sections. Recent tests, however, have shown that the frame sections may be fabricated from 1/16-inch instead of $\frac{1}{8}$-inch steel, or that only one $\frac{1}{8}$-inch-thick steel frame section may be used provided the shadow mask is welded rather than clamped to the frame. Either change reduces the weight of the assembly and the amount of material used, with a resultant lower cost, and allows the tube to be exhausted faster because of the reduction in volume of metal inside the evacuated envelope.

A circular frame is used because this configuration gives the strongest frame for the least amount of metal. It has been demonstrated, however, that the design principles described may be applied to rectangular frames if desired.

Phosphor-Dot Plate

The phosphor screen is printed on a 3/16-inch "grey" glass plate cut to match the contour of the frame, as shown in Fig. 16. The sharp edges of the plate are ground off to remove areas of high stress concentration which might cause the glass to fracture during subsequent processing. Three radially directed *V* grooves are ground on the periphery of the plates spaced 120 degrees apart; these grooves can be seen in Fig. 16.

Fig. 17 is a view of an early set-up used to grind the *V* grooves in the plate. The grinding wheel was a Norton 280-grit-abrasive wheel, dressed to the desired groove contour. Soluble oil was used as a lubricant. As mentioned before, the dimensions, spacing, and location of the grooves are not critical.

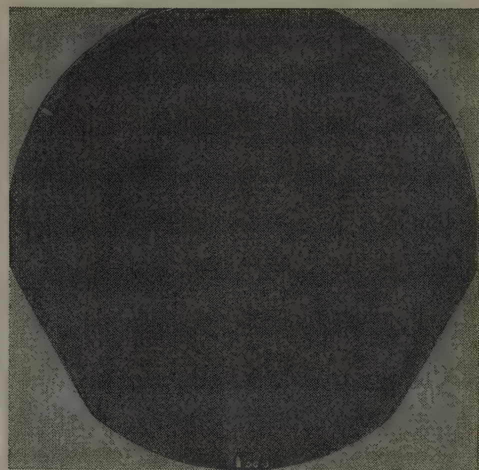

Fig. 16—Plan view of glass phosphor-dot plate.

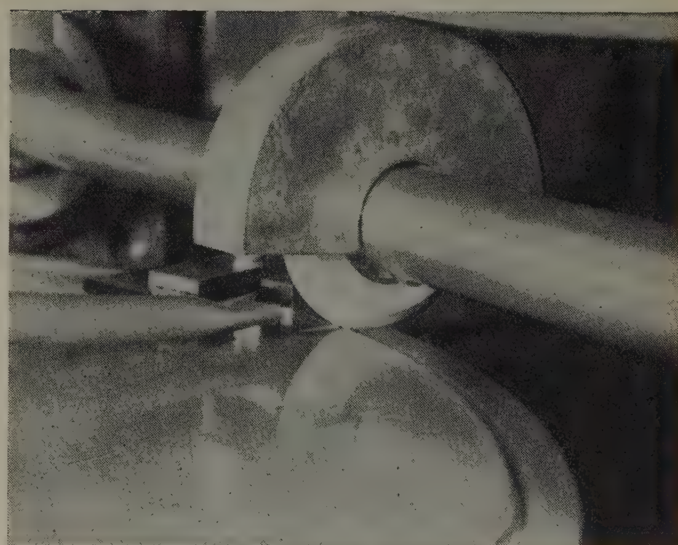

Fig. 17—Grinding grooves in phosphor plate.

The three different phosphors are applied to the glass plate by the use of essentially the same silk-screening techniques described by Freedman and McLaughlin.[2] Several modifications, however, are worth noting. In the old technique, it was necessary that the registry marks (slot and dot) on the screening stencil be aligned accurately with the two reamed holes in the glass phosphor plate. Any misalignment at this stage resulted in misregistration between the phosphor-dot trios and the aperture in the finished screen assembly. With the new adjustable screen unit, three registry marks on the

screening stencil corresponding to the location of the *V* grooves in the phosphor-dot plate are merely referenced with the three *V* grooves in the glass. The degree of registration between the registry marks and *V* grooves is not critical because the phosphor plate can be shifted horizontally in the finished assembly by rotating the eccentric pins.

In order to align the finished aluminized phosphor-dot plate with the apertures in the mask-frame assembly, it is necessary to have areas of the plate unaluminized and screened with only one of the three dot arrays.

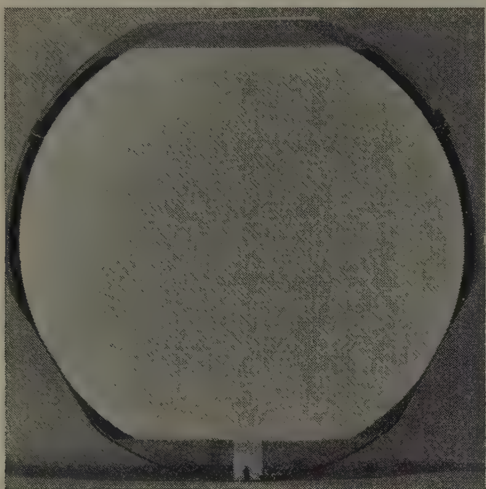

Fig. 18—Finished phosphor-dot plate.

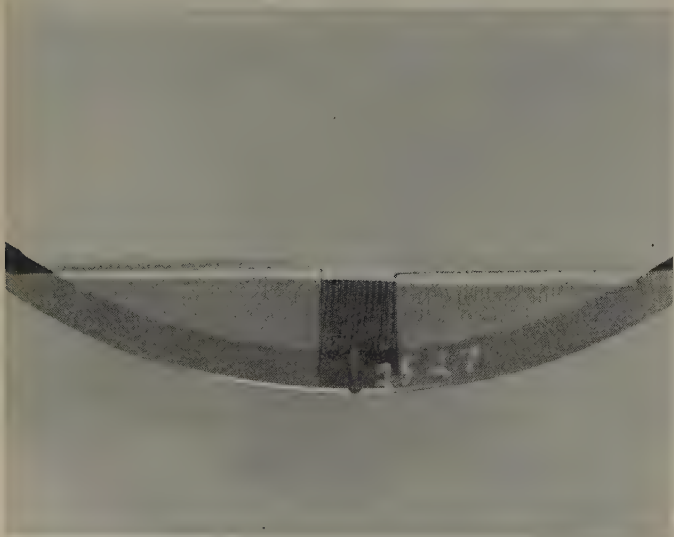

Fig. 19—Close-up of phosphor-dot plate showing alignment area.

These areas are readily seen in Fig. 18, which is a photograph of a finished phosphor-dot plate. During the adjustment of the eccentric pins, the operator sights through these alignment areas to determine when the dot-trios and apertures are in registry. Fig. 19 is a close up view of one of these unaluminized areas. The aluminum band running to the *V* groove is an electrical connection between the main aluminized area and the eccentric pin. The unaluminized areas are hidden by the decorative mask in the finished tube.

Fabrication of Mask-Frame Assembly

The procedure for making the new viewing-screen assembly is as follows:

When a shipment of shadow masks is received from the photoengraver, the masks are inspected by an electronic device (a densitometer) to determine whether the apertures are within specifications and are also inspected visually for general appearance. After inspection, the masks are chemically treated to blacken the surface, and are then ready to be "hot-blocked" to the frame.

The mask is laid on the lower frame section so that the three elongated radial slots in the border straddle the three eccentric pins, which have been placed in their respective collets. Because there are six possible ways the mask could be placed on the frame, two identifying tabs are provided on the border to assure proper location of the array in the frame. Fig. 20 shows the mask properly located on the frame. It is general practice to place the large identifying tab at the bottom and the smaller tab to the left. The upper frame is placed over the mask, and 24 screws are placed in the tapped holes but not drawn up tight. Because the screws have not been tightened, the large round holes and the elongated radial holes allow the mask to expand radially with respect to the frame. This loose assembly is then placed in the equipment for "hot-blocking." In this equipment,

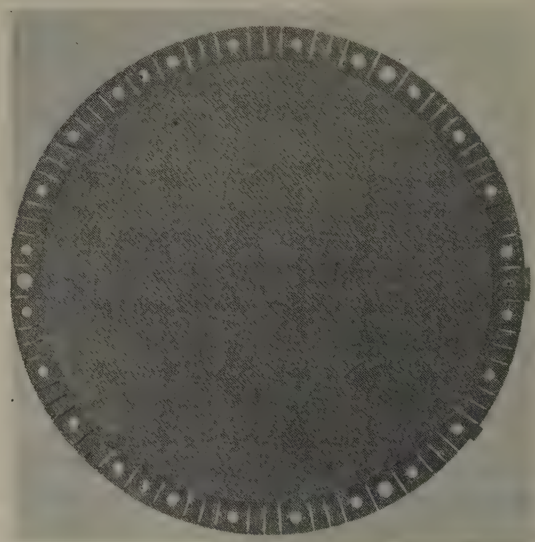

Fig. 20—Shadow-mask positioned on frame.

a heated platen is just below the mask. An upper platen, also heated to a predetermined temperature, is lowered, applying a slight pressure to the mask, and thereby heating it while the frame remains at approximately room temperature. While the mask is in the expanded condition, the clamping screws are tightened by an air-driven driver. The upper platen is then lifted, and the mask-frame assembly is removed from the equipment.

Cooling of the mask places it under tension, which serves to hold it flat.

After cooling, the mask-frame assembly is checked for mask tension by measurement of its resonant frequency. If the tension is satisfactory, the assembly is checked against a master phosphor plate to determine whether it meets the interchangeability requirement. Rejected assemblies are taken apart and "hot-blocked" again, and are usually satisfactory on retest.

In the old assembly it was found that all the masks were slightly distorted after "hot-blocking." This distortion was attributed to the continuous rim of cold metal surrounding the expanded mask formed by the solid border of the mask, which was in contact with the cold frame. Breaking up the continuous rim of metal by a series of narrow radial slots corrected this undesirable condition.

Printing of Phosphor-Dot Plate

In the discussion of the preparation of the phosphor-dot plate, it will be assumed that a gelatin screening stencil such as that described by Freedman and McLaughlin[2] or a more durable metal stencil has been prepared.

The grooved phosphor plate is positioned on the movable base of the silk-screening table by the use of a special jig with six pins, and is secured in position by means of a vacuum chuck. The table and positioning jig are shown in Fig. 21. Three pins of the jig mate with the V grooves in the glass plate, and the other three pins fit locating grooves in the printing-table base. The

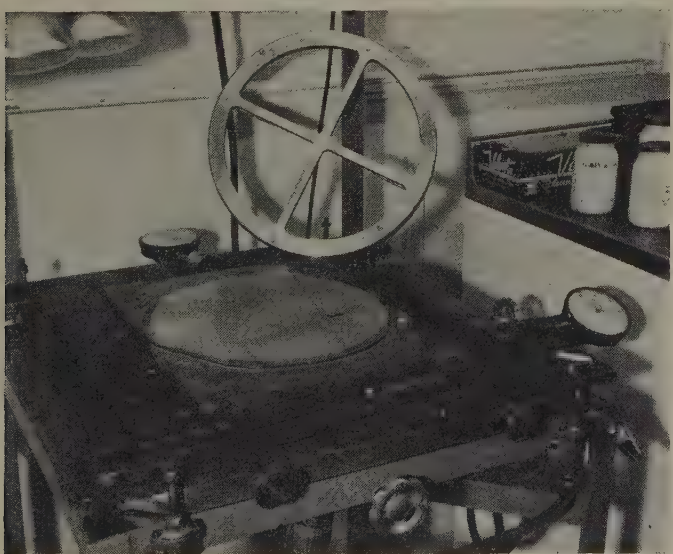

Fig. 21—New screening table showing positioning jigs.

screening frame with the dot pattern properly positioned on it is placed over and in contact with the glass plate. Incorporated in the pattern are three dots which correspond to the location of the three V grooves. For the initial set-up of the table, these dots are positioned over the V grooves by moving the compound on the screening table. Once set, this adjustment need not be made again for the life of the stencil. As mentioned before, the alignment of the phosphor-dot plate with the stencil need not be exact, but only within the adjustment permitted by the eccentric mounting pins.

With the stencil and phosphor plate in contact and aligned, a phosphor paste for one of the three colors is forced through the stencil with a rubber squeegee.

In the early method, the screening frame was lifted off the phosphor plate by hand. At present, however, a pneumatic piston arrangement engages the screening frame and snaps the stencil off the phosphor plate. This quick mechanical removal results in a superior print and requires less operator skill. After the first printing, the screening frame is transferred to an automatic cleaning machine which thoroughly removes the adhering phosphor paste so that the same stencil can be used in applying the next color without one color contaminating another.

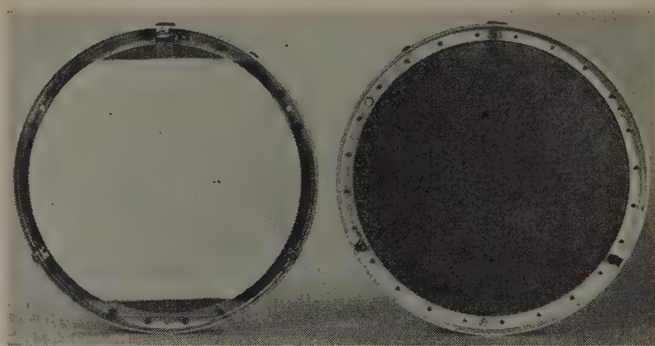

Fig. 22—Front and rear views of new viewing-screen assembly.

After one color phosphor has been printed, the cleaned stencil is returned to the screening position over the glass plate. The glass plate is then moved by means of special cross-feed and dial gages so that the stencil holes are over the correct position for the second color to be applied. After the second set of dots is printed, the phosphor dots are wiped from the top and bottom portions of the array to form the areas which will later be used in the alignment of the phosphor plate with the mask-frame assembly. The third color paste is "squeegeed" in the same manner as the other two. Unlike the earlier screens, which required two or three layers of each phosphor paste, the present phosphor screen is completed with the application of a single layer for each color.

The screened phosphor plate is completed by baking, silicate spraying, filming, and aluminizing, using the methods described by Freedman and McLaughlin.[2] The finished phosphor-dot plate is aligned with the shadow mask in the alignment lighthouse and the eccentric pins are locked in place. Three small clamps are added to secure the phosphor plate to the assembly. The unit is then completed and ready to be bolted to the cone.

Fig. 22 shows front and rear views of the improved viewing screen assembly. Fig. 23 shows a close-up view

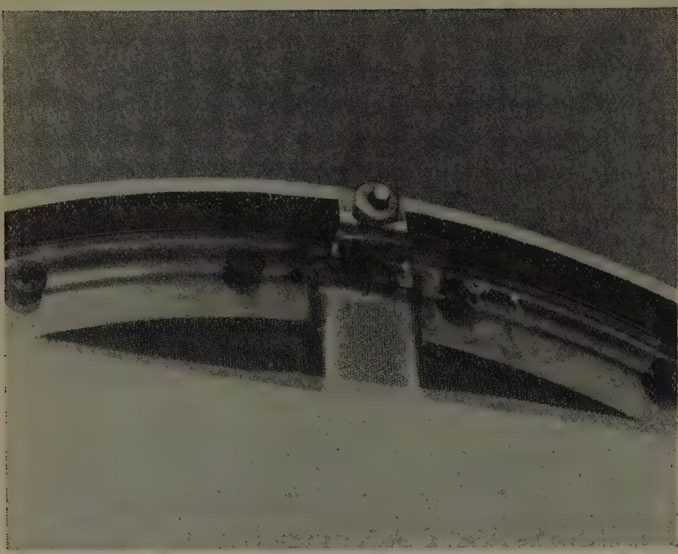

Fig. 23—Close-up view of hold-down clamp of phosphor-dot plate.

Fig. 24—Close-up view cf collet.

of the hold-down clamps for the phosphor-dot plate. Fig. 24 is a close-up view of the collet.

Summary of Improvements in Viewing-Screen Assembly

The new viewing-screen assembly fulfills the three basic objectives mentioned previously:

1. The performance of the tube has been improved. This assembly gives a brighter picture as a consequence of the higher power-dissipation capability of the mask and the improved screen-processing techniques. The colors are purer because the quality of the shadow-mask has been improved. The registration between the phosphor-dot trios and apertures is better, and the assembly is more stable.

2. Interchangeability between the parts is now a reality.

3. The cost of the parts of the improved assembly are a fraction of the cost of the parts for the old assembly because precise dimensions are no longer necessary. The parts can now be fabricated to commercial tolerances by simple production tools.

Improvements in Envelope and Processing

In addition to the development work on the viewing-screen unit, work has been carried forward on the envelope and on processing techniques.

Notable among the improvements made in the envelope design has been the removal of the internal magnetic shield from the tube. This removal has many advantages. Although a magnetic shield is still required, it is external to the tube and is part of the television receiver, thereby allowing the receiver designer to tailor-make the shield to suit the particular magnetic field conditions in his receiver. Also, lower-cost silicon steel may be substituted for MuMetal. The removal of this shield has also lowered the tube cost by removing from the evacuated space metal which would normally have to be degassed during the exhaust process. Part of the four-to-one reduction of the exhaust cycle on this tube relative to the early design can be attributed to the removal of this shield.

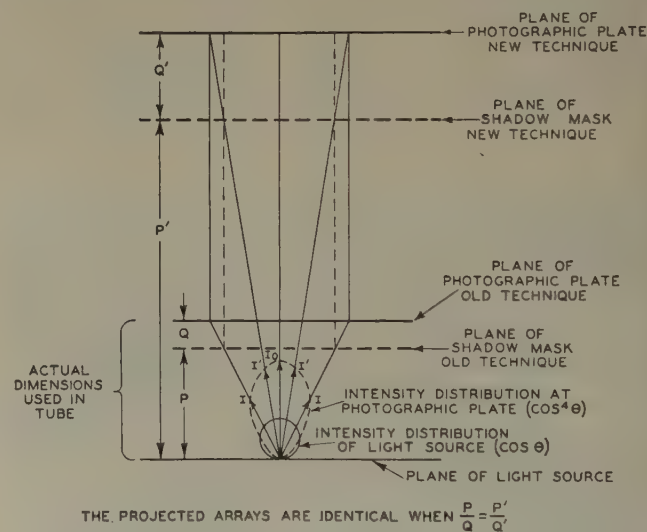

Fig. 25—Diagram of improved photographic lighthouse.

A modified lighthouse photographic technique has been an important processing improvement. This improvement has resulted in a higher quality stencil and, consequently, in improved phosphor-screen quality. In "old-design" tubes, the dots at the center of the pattern were very often larger than the dots at the edge. This condition resulted because the nonuniform distribution of the light intensity across the photographic plate caused it to be exposed nonuniformly. Fig. 25 illustrates this problem. The light intensity at the edge of the photographic plate is only 73 per cent of the light at the center due to the normal change in intensity with angle. This condition was remedied by the develop-

ment of a new "lighthouse." In the new "lighthouse," also illustrated in Fig. 25, the spacing between the mask, photographic plate, and light source is expanded by three-to-one ratio. This expansion reduces the effective angle to less than 10 degrees. As a result of this new arrangement, the edge dots receive 96 per cent of the light intensity of the dots at the center; the dots on the photographic plate, therefore, are uniform in size.

The equipment used for cleaning the stencil between printings has also undergone considerable improvement. For early color tubes, the stencil frame was removed to a cleaning hood after each phosphor application and was carefully cleaned with expensive industrial cleaning tissues saturated with amyl acetate to insure freedom from color contamination. Absorbent paper-toweling sheets were placed underneath the stencil to absorb both the solvent and the phosphor powder. The screen was washed a minimum of three times; fresh tissues and absorbent paper sheets were used each time, and the acetate was thrown out with the cleaning tissues. This cleaning process was slow, costly, and not always thorough.

Present equipment for cleaning the stencil frame is automatic; cleaning takes about one-quarter of the time of the previous manual method. In the automatic washing equipment, two frames are cleaned at one time. The frames are held in a vertical position and are sprayed by the cleaning solvent for one minute through an array of jets. The spray of solvent shuts off automatically and is followed by a spray of drying air from the air jets. The drying time is two minutes. The used cleaning solvent is collected, filtered, and re-used. This new equipment is rapid, economical, and thorough.

The electron-gun assembly has not been changed in basic design, but refinements have been made to improve ruggedness, centering in the neck tubing, and high-voltage operating characteristics. The improved high-voltage operation was obtained by the use of a new stem design and barrier base.

Experience has shown that it is no longer necessary to use the shrunk-neck tubing recommended by Barnes and Faulkner.[4] This change constitutes a considerable cost saving.

The envelope assembly has been changed to simplify manufacturing and improve space utilization. A glass envelope developed by the Corning Glass Works in conjunction with RCA replaces the metal envelope used in the early design. The glass envelope shown in Fig. 26 consists of a two-piece assembly similar to the metal envelope. Both the inside and outside of the viewing surfaces are ground and polished to remove mold marks. The faceplate section is similar to that used on black-and-white kinescopes. Metal welding flanges are sealed to both the face-plate section and the cone section to close the assembly. These flanges are heli-arc welded after the viewing-screen unit is inserted. Three studs welded to the flange on the lower section provide means for fastening the viewing screen to the envelope assembly. Because the faceplate section is fabricated with straight sides, the diameter at the face of the tube has been reduced from $15\frac{7}{8}$ inches to $14\frac{5}{8}$ inches with no loss in picture size. This modification improves space utilization in the receiver cabinet.

Fig. 26—New glass envelope.

After the final envelope seal (the main weld) is made, the tube is exhausted by slightly modified conventional cathode-ray-tube methods. When first produced, tricolor kinescopes were evacuated on single or double fixed-position exhaust stations. The exhaust equipment now utilized is of the straight line variety. In this equipment, there are 32 pumping positions; the tube, mounted on its individual pump cart, moves successively through these positions. The present schedule is designed to produce a tube every $2\frac{1}{2}$ minutes. This rate represents a fourfold increase in speed over that of the straight line equipment first utilized. The modifications to the exhaust cycle used for standard black-and-white kinescopes are:

1. Reduced heating and cooling rates are advisable. Slow heating and cooling of the phosphor-dot plate is required to avoid breakage from thermal shock. In addition, the behavior of the mask-and-frame assembly during the thermal cycle makes slow cooling desirable. As the tube is heated, the mask tension is reduced because the coefficient of expansion of the mask is higher than that of the steel frame. When the cooling phase of the cycle is begun, however, the mask cools more rapidly (by radiation) than the rather massive frame. If the tube is cooled at a rate normal for black-and-white kinescopes, the temperature of the mask may fall sufficiently far below the temperature of the frame to put the mask under greater tension than its initial value. Under these conditions, the stress may be sufficient to stretch the mask beyond its elastic limit.

The desired results have been achieved by modification of the exhaust equipment used for black-and-white kinescopes. The slow heating cycle is established and the tube is automatically tipped-off at 300 degrees C. The tube is then moved to a cooler for the slow cooling part of the cycle. During the entire exhaust operation, the face of the tube is shielded from radiant heat, thereby preventing nonuniform heating of the phosphor-

dot plate which might cause it to crack. The increase in exhaust speed over that of the straight line equipment first utilized has been made possible by the removal of mass from the screen assembly, by the removal of the internal magnetic shield, and by improved parts-cleaning methods.

2. Because the exhaust cycle is longer than that used for black-and-white kinescopes, activation of the cathodes is performed for a longer time at a lower temperature.

Experience has shown that these assembly, exhaust, and processing techniques, in general, are practicable with either glass or metal envelope tricolor kinescopes.

Another minor but important improvement is a change in the styling of the decorative mask. A new decorative mask within the tube envelope has been designed which can blend more readily with the decorative mask within the receiver. The color of the mask has also been changed from flat black to a more pleasing dull grey.

A photograph of the new improved version of the RCA tricolor kinescope is shown in Fig. 27.

Fig. 27—RCA tricolor kinescope.

Acknowledgment

The authors wish to acknowledge the contributions of the great number of engineers both at RCA and at various vendors whose work made possible the developments described in this paper.

The CBS-Colortron: A Color Picture Tube of Advanced Design*

N. F. FYLER†, ASSOCIATE, IRE, W. E ROWE† AND C. W. CAIN†

Summary—**This paper describes a three-gun, tricolor picture tube of basically improved design. Its picture is presented on phosphors appplied directly to the curved internal face of the tube. With a curved screen, a curved mask which is self-supporting is used. The mask and the springs to hold it in place weigh only six ounces. This simple, light, yet rugged structure is mounted directly on the face plate. Three small "V"-shaped surfaces on the mask rest on three hemispheres molded directly on the glass to locate the mask precisely. No adjustment is required at assembly. The phosphor dots are placed directly on the curved glass face plate by a photographic process, using the individual mask belonging to that tube as a negative. The screen will always exactly register with its mask because they are images of one another. The curved screen face plate serves also to close the envelope just as it does in the black-and-white tube.**

Advantages resulting from this design are discussed. The improvements in mechanical simplicity, ease of manufacture, size, weight, thermal-stability, electron optics, picture quality, and circuit stability are shown to stem from the use of a spherical mask and a spherical face plate. The performance of a developmental tube of this design is given. The practicability of alternate forms of this tube. including rectangular screen types in rectangular bulbs is examined. The possibility of using much of the conventional factory equipment for black-and-white picture tubes to make this new color tube is discussed.

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Introduction

THE SATISFACTORY MEANS of reproducing a color picture persists as a major problem to be solved before mass-produced, low cost, compatible, high quality, large screen color television is available to the public. Of the various methods proposed for achieving color television pictures, the cathode-ray tube method appears most promising, and receives most attention from the industry.

In the presence of millions of black-and-white receivers in use, compatibility is no longer a question for debate. A suitable cr tube, if it is to be accepted generally, in addition to answering the requirements of a good color picture, must answer the requirements of compatibility.

Previous to the time of this writing, only two types of color tubes have been used to demonstrate publicly accepted color pictures.[1,2] Of these, only one has been developed to the point where plans have been announced for its manufacture and has shown in public

[1] H. B. Law, "A three-gun shadow-mask color kinescope," Proc. I.R.E., vol. 39, pp. 1186–1194; October, 1951.

[2] R. Dressler, "The PDF chromatron—a single or multi-gun tricolor cathode-ray tube," Proc. I.R.E., vol. 41, pp. 851–858; July, 1953.

demonstrations that it fulfills simultaneously the requirements of acceptable picture quality and compatibility.[3] This tube, a tri-gun, tricolor, shadow mask picture tube with a planar shadow mask and a flat phosphor plate assembly mounted in the bulb interior as a unit, has proved to be a useful tool for studying technical problems such as the NTSC signal standards.[4] However, as a result of investigations in the laboratories of CBS-Hytron, it appeared that this tube, along with other color tubes announced thus far, has certain major disadvantages as to size, cost, and shape, all of which stem inherently from their basic design; namely, the planar or flat-mask type of construction.

To overcome these disadvantages, CBS-Hytron early undertook development of a shadow-mask picture tube which could be manufactured at less cost than previous types and could be readily made in the rectangular shape and large sizes now common to black-and-white picture tubes. The first step was to develop a photographic process that would make it possible to apply the phosphors directly to the curved internal face of the tube. It was foreseen that with a curved screen, a curved mask which is self-supporting might be used. This would lead to a structure so light that it could be mounted directly on the face plate. This combination of a curved mask and a curved screen would have many advantages in mechanical simplicity, ease of manufacture, size, weight, thermal stability, electron optics, picture quality, and circuit stability. A photographic process for applying the phosphors directly to the face plate has been developed. Tubes of this type have been made and tested. The results indicate that many of the anticipated advantages have been realized.

The purpose of this paper is to describe the design, the construction and the principles of operation, and to analyze the advantages of this form of color tube.

Principle of Operation

The present color tube uses the familiar principle of masking the beam to obtain color selection.[1] Three guns located in a symmetrical cluster in the neck of the tube provide three separately modulatable or variable electron beams; one for each primary color: red, blue, and green. The beams are arranged to strike a viewing surface made up of phosphor dot trios of the corresponding primary color light emitting phosphors on a glass surface. Between the guns and the phosphor screen is placed a thin perforated diaphragm called the mask which is so arranged as to partially block off the phosphor array from the electron beams. The perforations or holes are of such size and alignment that, for instance, the electron beam that is to excite the phosphor for the red portion of the color picture is allowed to strike only the red emitting phosphor dots. In like manner, the blue and the green beams are restricted to strike their appropriate phosphor dots. This masking action is schematically illustrated in Fig. 1. Thus, color separation is achieved by masking and control of direction-of-approach of the three converging electron beams. Proper convergence requires that all three beams meet at a common point on the mask. In the planar mask tube, it has been the practice to apply variable focusing and convergence voltages to compensate for the different lengths of the beam as the raster is scanned. These variable voltages, called dynamic focus and dynamic convergence, are superimposed on the steady-state voltages of the respective electrodes.

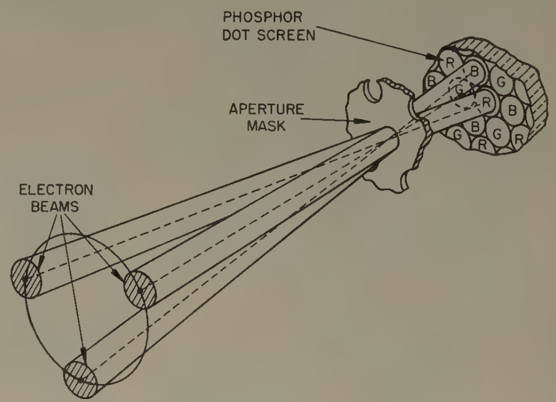


Fig. 1—Relationship of electron beams, shadow-mask, and phosphor dot array in a tri-gun shadow-mask color tube.

In the present tube the picture is presented on the phosphors applied directly to the curved internal face of the tube, and a matching curved mask is used. As may be seen from Figs. 2a and 2b, this affords ideal conditions for focus and convergence of the three electron beams. The curved field consideration, important in black-and-white tubes, is many times more advantageous in multi-gun color tubes. When this radius of curvature nearly approaches that of the swing of the beam, much less dynamic correction of focusing and convergence is required. This will be made clear by the following analysis.

Fig. 2a illustrates the electron beam focusing conditions in a simplified geometry where the beam is assumed to bend abruptly at the deflection center. With this simplification, it can be assumed initially that the beam is focused at the center of the picture area of a tube. As it is deflected from this point, if the landing area were considered as a plane perpendicular to the major axis, and if no lens correction is applied to change the focal length, the locus of optimum focus will not coincide with the plane. To a first approximation, this locus falls on a spherical surface with an approximate radius of curvature equal to the distance from the deflection center to the center of the picture area. There are many factors that alter this simple relationship, including departure of actual deflection from the simple geometry shown. In addition, the electron beam sources are off center from the tube axis in a practical multi-

[3] Petition of RCA before the FCC; June 25, 1953.
[4] C. Hirsch, W. Bailey, and B. Loughlin, "Principles of NTSC compatible color television," *Electronics*, pp. 88–89; February, 1952.

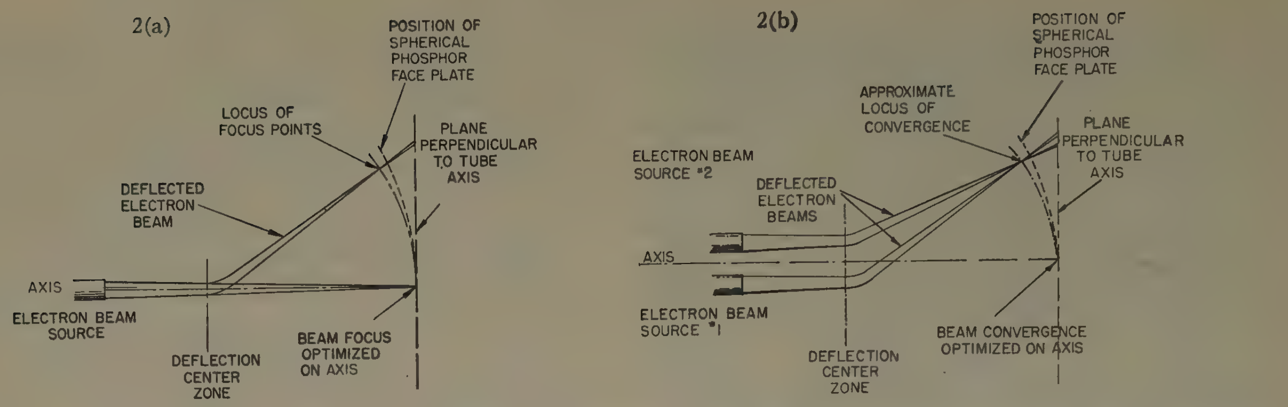


Fig. 2—Electron optics of focus and convergence. (a) Schematic conditions of focus. (b) Approximate schematic conditions of convergence.

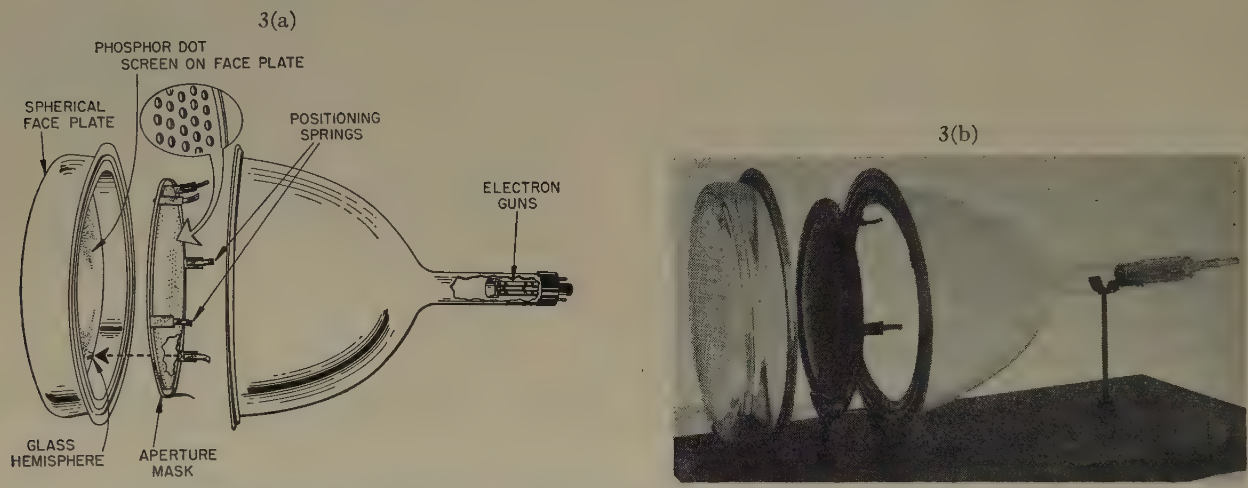


Fig. 3—"Exploded" view of CBS-Colortron. (a) Photograph. (b) Schematic.

gun tube. The locus of optimum focus for all three beams are not identical. It is clear, however, that if the phosphor plate were curved in an arc very nearly equal to the approximate optimum radius described, a reasonable engineering compromise would be achieved.

The convergence problem in the three-beam shadow mask tube is even more serious than the focus problem. As previously stated, convergence requires that the beams shall strike the mask together at the same point everywhere on the raster. This condition is schematically represented for two beams in Fig. 2b. Unless a correction is applied, the error in convergence is very great for a planar mask tube. In the case of the curved mask tube, the error in convergence is greatly reduced. Even more important from a practical standpoint, if the dynamic convergence is improperly adjusted, the error in convergence will be many fold greater for the planar mask tube than it will be for the curved mask tube.

Basic Design

The CBS-Colortron has three main differences of design that set it apart from other color tubes. One, the phosphor array is produced directly upon the spherical glass face plate of the tube. Two, the aperture mask is also spherical and has such a radius of curvature that a nearly constant radial distance is maintained between its surface and the face plate. Three, the aperture mask is uniquely positioned with its three "*V*"-grooves mounted directly upon three hemispherical glass molded studs which are an integral part of the face plate. The aperture mask of unitized construction is retained by simple leaf springs, and is further stabilized by three thin metal hemispheres, welded into position, that bear in compression against the face plate. These features are shown in Figs. 3a and 3b. The basic design features of the "*V*"-grooves, the hemispherical glass studs, and the retaining springs referred to above are shown in Figs. 4a and 4b. The completed tube is shown in the photograph Fig. 5. The size of the tube was set by the available 15 inch diameter bulb. The radius of curvature of the face plate is approximately 22 inches inside. The over-all length of the bulb is approximately 26 inches. The diameter of the useful picture area is approximately 12 inches. The center of deflection is approximately 17 inches from face plate surface. The face plate is curved in a spherical form as is required for bulb strength. The texture of the inner surface of the face plate is similar to that used for black-and-white panels or face plates; it need not be optically perfect or polished.

As will be described in detail later, the screen is applied to the internal surface of the face plate by settling and then caused to adhere at the desired areas by a

photographic process. Some of the advantages derived from producing the phosphor dots by settling and photo-sensitizing are of an optical rather than a geometrical nature. They lead to maximum brilliance, truest hues, and maximum picture contrast.

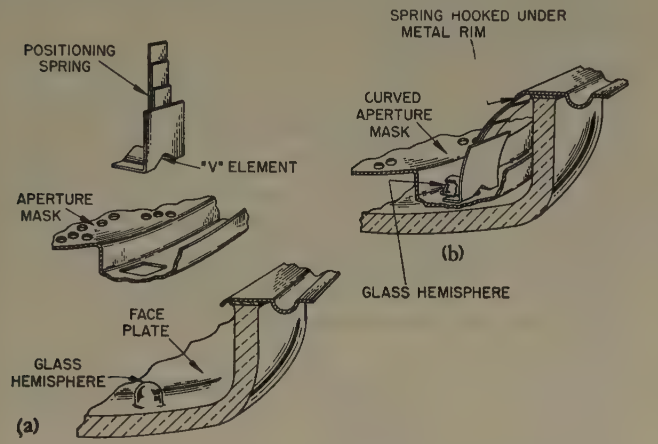


Fig. 4—Details of mounting spherical shadow mask. (a) "Exploded" view of mounting structure. (b) Sectional assembly showing position of leaf springs.

Fig. 6a shows a typical profile of a phosphor dot applied by the new settling and photographic process. Figs. 6b and 6c show typical profiles of phosphor dots applied by the conventional "silk screen" or stencil method. If it is conceded that there is an optimum thickness of phosphor and that thorough coverage is required for optimum brightness, it would follow that it is important to maintain a phosphor deposit in a level "plateau" contour as shown in Fig. 6a. This condition is readily set up and controlled by the new screen method described.

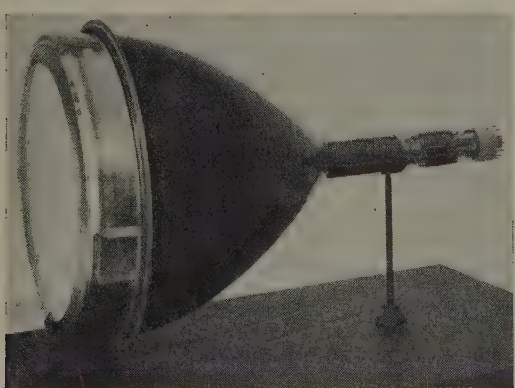


Fig. 5—Photograph of completed CBS-Colortron.

It is well known in black-and-white tube practice that the thickness of the phosphor influences the color. In the case of black-and-white tubes, compensations are readily made; but in the case of color tubes where primary colors are desired, it is difficult, if not impossible, to offset color deterioration of the type to be described. The maximum coverage and uniform thickness characteristics of the new screening method give the best compromise for color. For proper color rendition, it is important to maintain a minimum and uniform thickness of phosphor consistent with requirements for brightness. This limitation is brought about by the yellow body color (by transmission) inherent in most practical color phosphors. The light, which is largely created in the phosphor array on the side opposite the viewer, has a tendency to shift in color as it passes through the phosphor. In particular, the red tends toward an orange hue, the blue tends toward green, green tends toward chartreuse. The trend increases with phosphor thickness.

It has been pointed out in previous studies[5] that settled phosphor screens give improved contrast.

There are other secondary advantages derived from having the phosphor array directly upon the face plate, such as a wide effective angle of view, and a considerable decrease in the over-all length of a practical tube.

Item 2 of the novel constructional features concerns the use and properties of a spherical mask. The spherical aperture mask is inherently self-supporting. This comes about from basic geometric considerations.

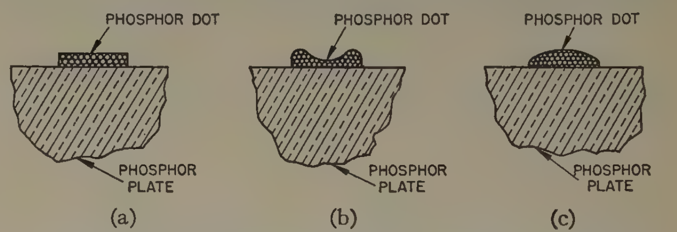


Fig. 6—Typical profiles of phosphor dots. (a) Shape of settled and photoformed dots. (b) and (c) Shapes of typical "silk screening" or stencil dots.

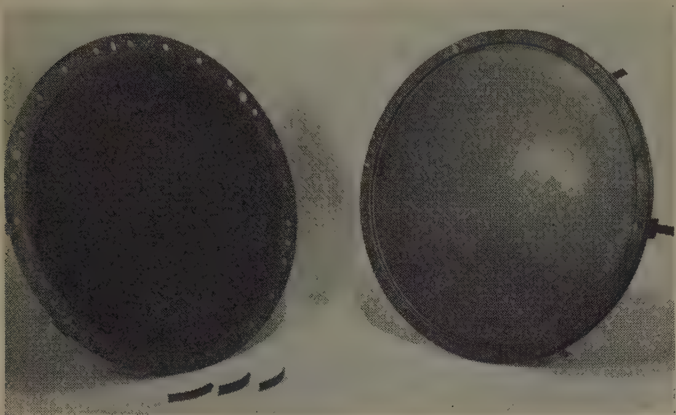
Stoker has shown that certain open convex surfaces are rigid. Open convex surfaces of positive Gaussian curvature, as well as closed convex surfaces, are rigid provided the deformation components are required to be uniformly bound; and that the deformations and the original surface should have a continuous third derivative.[6] He established further that holes introduced in such a surface did not alter its behavior.

The spherical aperture mask is also inherently free from misregistry due to heating. A theory of the thermal-response properties of a spherical mask is developed in the Appendix. In summary: Because the curvature of the mask is predisposed toward the face plate, a rise in temperature on any portion causes a displacement that is of such nature as to maintain registry. The color deterioration defect of an increase of the center-to-center distance of adjacent apertures due to heating is very nearly cancelled by an accompanying movement of the heated area of the mask toward the face plate. As brought out in the analysis, this corrective deflection effect is present whether the mask is heated as a whole, or is heated in local zones.

[5] R. R. Law, "Contrast in kinescopes," Proc. I.R.E., vol. 27, pp. 511–524; August, 1939.

[6] J. J. Stoker, "Studies and Essays Presented to R. Courant On His 60th Birthday, January 8, 1948," Interscience Publishers, New York, N. Y., pp. 407–419.

Satisfactory developmental tubes have been made using either glass or metal spherical masks. Fig. 7a shows a mask fabricated from a "Photoform glass" developed by the Corning Glass Company. Fig. 7b shows a mask made from metal. It is impossible at this time to say which structure will be preferred, but due to the ready availability of the metal mask, the discussion will be centered on this type.



(a) (b)

Fig. 7—Photographs of two types of spherical shadow-masks. (a) Mask made entirely of photoform glass with simple retaining springs. (b) Sheet metal mask assembly showing retaining springs and "V"-channels.

Item 3 of the novel constructional features concerns the method of mounting the mask. Because the mask is lightweight and self-supporting, and is used to produce the image of the phosphor dot array by a photographic process, the mounting need only answer these requirements: the mask must be uniquely located; it must resist shock; it must provide for expansion during the various heat treating processes; and must provide for easy insertion and removal. A minimum of picture width is to be subtracted.

Figs. 4a and 4b previously referred to illustrate the mounting scheme used. Three molded hemispherical studs of glass which are an integral part of the face plate near the edge of the picture area are provided. Three metal "V"-channels are welded to the metal mask flange. A compression spring which is welded to the rim of the mask to become an integral part is also shown. In the design here discussed, leaf springs are used. These springs are constructed of a welded laminate of thin spring stock. This particular form of spring has the advantage over other types of compression springs tried in that it is simple, easy to fabricate from strip material, easy to rigidly attach to the mask form, and gives a large latitude in permissable deflection. In the completed tube, these springs absorb shock, as they will at all times press the "V"-channels against the hemispherical glass studs. With this mounting, the mask assembly becomes one unit part and needs only be uniquely located to maintain registry.

The principle used to achieve unique location of the mask with respect to the face plate is based on the kinematic design principle that a body must have at least "$6-n$" points of contact with a second reference body if it is to have only "n" degrees of freedom, relative to the reference body.[7] In this case, each "V" makes two points of contact with each glass hemisphere so that "n" equals six and there are no degrees of freedom. Thus, unique location is obtained with only moderate tolerances of the parts.

As will be brought out later, with this design the ultimate size of the tube is not seriously limited nor is the shape of the mask or bulb greatly restricted. For instance, rectangular framed masks for rectangular tubes such as shown in Fig. 8 are possible. The analysis indicates that the response to heat is such that color deterioration is not anticipated (registry is not lost) with wattages or screen dissipation up to the limit of current that can be drawn from existing cathode-ray guns.

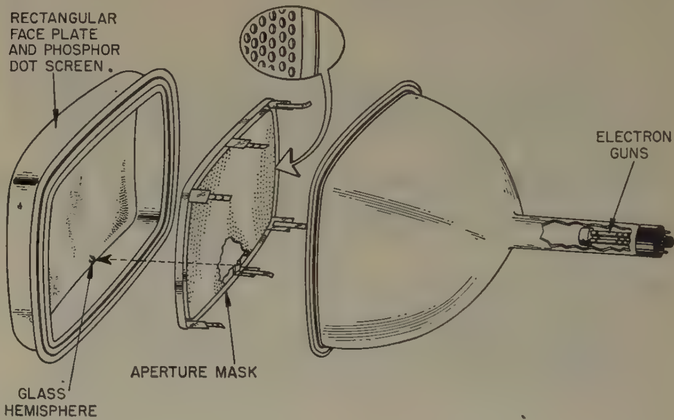


Fig. 8—"Exploded" view of proposed 21″ rectangular tube.

The electron gun used in the developmental Colortron is similar to one that has already been described.[8] The improvements of shadow mask and phosphor plate and mounting arrangement already cited have altered the picture so that to the manufacturer and to the would-be user of this form of color tube, the gun represents possibly the most critical item, and presents an area of future improvement.

Construction and Processing

A logical place to start discussion of construction and processing is with the phosphor screen. A new technique which is simple, accurate, and appears to be ideally suited for mass production processes is used for depositing the phosphors on a curved surface. The method employs a photographic technique which is similar to photoengraving, and a settling technique very similar to that used in making black-and-white screens.

The face panel, which has a texture as produced by the glass molding process, is cleaned in a manner similar to black-and-white practice; strong detergents and suitable chemicals are applied.

[7] J. Strong, "Procedures in Experimental Physics," Prentice-Hall, Inc., New York, N. Y., pp. 585–586; 1945.

[8] H. C. Moodey and D. D. VanOrmer, "Three beam guns for color kinescopes," Proc. I.R.E., vol. 38, pp. 1236–1240; October, 1951.

The screen is initiated in each step by settling a color phosphor of a particular color on the face plate. One of the desired three primary color phosphors is allowed to settle over the entire screen from an aqueous suspension. For this operation the panel is positioned with the viewing side down. After settling, a suitable photosensitive material is coated over the phosphor. This surface is then exposed to a suitable light source through the curved aperture shadow mask that is to be used for that particular tube. Thus, the shadow mask itself serves as a negative to make its own image on the phosphor. No intermediate "master" is used to introduce error. The requirement in a production run that all the masks be identical is eliminated. The shadow mask is prepared in advance by completely annealing so that it will be strain free. Its surface is treated to produce a black "satin" finish to improve emissivity. The springs and the "*V*"-grooves are welded into position after the above annealing.

The mask can be inserted and removed from the face panel in a matter of seconds. This feature is important, in that four insertions and three removals must be accomplished before the tube is completed. At the start of this process the mask is identified with a particular panel and a particular "*V*"-groove is singled out for a particular supporting hemisphere. As previously shown in Fig. 4b, mounting is accomplished when the six leaf springs are "hooked" under the metal rim.

In the photographic exposure, the light source simulates the size and position of the electron beam in the finished tube. After exposure, a development process is used which allows the material in the area that was not exposed to light (shielded by the solid structure of the aperture mask) to be washed away completely. In the areas where the light image was produced on the phosphor layer, the photosensitive material has a property of retaining the phosphor through the development process. Thus, one complete phosphor dot array containing the phosphor material necessary to produce one of the primary colors is placed on the screen.

By depositing over the entire screen another layer of a different color phosphor, and by using the same aperture mask placed in exactly the same position, but with the exposing light source moved so as to coincide with the electron beam of a second gun appropriate to the color of the phosphor settled, the former process is repeated. Thus, a second, and subsequently a third phosphor dot array is obtained to complete the phosphor dot screen. This technique will produce a phosphor array in proper registry directly on the face plate, independent of its shape or curvature, as long as the curvature of the aperture mask and face plate are appropriately matched.

To increase the brightness of the picture and to stabilize the screen potential during operation of the tube, the color screen is aluminized. This involves the use of a barrier layer and a process of evaporating aluminum to give a uniform thin film of such thickness as to achieve maximum brightness from the screen.

The open structure of the panel at this stage gives rise to an advantage in these processes as compared with the usual black-and-white tube because the screen can be examined with ease.

While the screen and mask assembly is being prepared the funnel section may be prepared. It is the practice to match funnels with panels as far as the diameter of the welding rim is concerned. This matching greatly facilitates assembly and welding.

The interior of the funnel is coated with a graphite coating similar to that used in a black-and-white tube and appropriately baked to remove volatile materials. This "dagging" extends down the neck region and overlaps the convergence cup electrode to form an electrostatic lens.

Various schemes have been successfully used for lining up the gun and the aperture mask so that good registry is produced. The tube may be readily re-gunned or repaired as is the practice with ordinary black-and-white cathode-ray tubes should that be necessary. In laboratory tests, a single tube has been re-gunned as many as three times without damage to the screen or the mask.

The assembly of the bulb is completed after gunning and welding of the main flange. After this operation, it is the practice to test for leaks. If the bulb is found free of defects, it proceeds to the exhaust operation.

It is at the exhaust operation that one of the major manufacturing advantages of the Colortron structure becomes apparent. Because of the type of mounting used for the mask and its low mass, the bulb temperature and the mask temperature rise very nearly simultaneously. The weight of the complete shadow mask assembly for the developmental tube here described is approximately 6 ounces. This compares favorably with the more than 6 pounds of the planar mask screen assembly. Thus, the new color tube can be exhausted at practically the same time rates and temperatures as current black-and-white tubes. Because the shadow mask is completely annealed, a given mask may be cycled an indeterminate number of times.

Design Advantages

The combination of a curved mask and a curved screen on the face plate as used in the CBS-Colortron gives a tube with many advantages over conventional planar-mask planar-screen tubes.

Because of its inherent simplicity, this tube is adapted to low cost, mass production methods. The simplified structure adds so few additional parts to those used in black-and-white tubes, that much of the existing production machinery may be used. Since the photographic process used to apply the phosphor screen to the face plate uses the individual mask belonging to that particular tube as the negative, the screen is produced in perfect registry. There is no need for expensive precision parts or painstaking alignment during assembly.

The three-ball three-"*V*"-block mounting provides

unique and exactly reproducible mask location. The simple structure is so light and so effectively mounted that the tube resists shock as well as its black-and-white counterpart.

The curved-mask, curved-screen combination simplifies receiver circuitry and adjustments. As the three beams sweep in an arc across the curved mask and face plate, they travel very nearly the same distance at the edges of the picture as they do at the center. This greatly reduces the need for dynamic convergence and focus, so that performance is more reliable, and installation and service are easier. Although the curved mask and screen radius does not match the deflection radius in the present developmental tube, the improvement is great. For a given error in adjustment of dynamic focus or dynamic convergence voltage, the error in focus or convergence at the screen is less than one-fifth that which would be observed in a planar mask tube.

The spherical mask resists overload. Being unstressed, it is not damaged by heating. Because registry is automatically maintained, any practical beam current may be used. Tests with beam currents in excess of three ma at twenty kv showed no visible change in registry even when the scanning was reduced to give a raster only three inches square. Detailed examination of the screen through a microscope with the tube operating at this power level showed no shift in the "landing" position of the beam. With such an arrangement the "guard ring" is clearly visible. Since the beam spot is approximately .012 inches in diameter and the phosphor dot is approximately .014 inches in diameter, the "guard ring" or region over which the beam may deviate without color contamination is about .001 inches wide. As viewed under a 75×, calibrated microscope, a shift in beam position of even a small fraction of the "guard ring" width would be clearly visible. Since no change was observed, it was concluded that any shift in beam position must be less than .0001 inches to .0002 inches. Such a shift is negligible and would give no misregistry. This same experiment was repeated with a "stretched" planar-mask tube, and not only did the colors shift badly due to misregistry, but the tube was permanently damaged.

Because the phosphors are applied directly to the internal face of the tube, this tube has a number of optical advantages. The face plate need not be of optical quality as it must be in the planar-mask tube where the picture is viewed through a "window." The contrast is improved because the screen is applied by settling and there are fewer reflecting surfaces between the picture and the viewer. This makes possible pictures with more nearly saturated colors.

Other features resulting from having the picture reproduced directly on the face plate are that no decorative mask is required and the tube length may be reduced for the same deflection angle.

And, finally, because the spherical mask is inherently self-supporting and stable, and the photographic process of producing the phosphor dots is just as easily and accurately performed on large tubes as on small tubes, a large size rectangular tube appears entirely feasible. This large color tube may be very little longer than the equivalent black-and-white tube, because an increase in deflection angle does not seriously increase the convergence and focus problems when an appropriate radius of spherical mask and screen are used.

Conclusion

The CBS-Colortron tube, which uses a light spherical aperture mask, and places the phosphor dot array upon the curved face plate has been described. The curved aperture mask and face plate give advantages in electron beam convergence, picture reproduction, simplicity of construction and manufacture. The advantages are dependent upon advanced photographic screen laying technique, to place phosphor dots upon the face plate and the exploitation of the properties of spheres and section of spheres.

The authors close with a quotation taken from context of "Religio Medici," by Sir Thomas Browne, which may have been applied all too literally: "for there is beauty whenever there is harmony, order, or proportion; and thus far we maintain the music of the spheres."

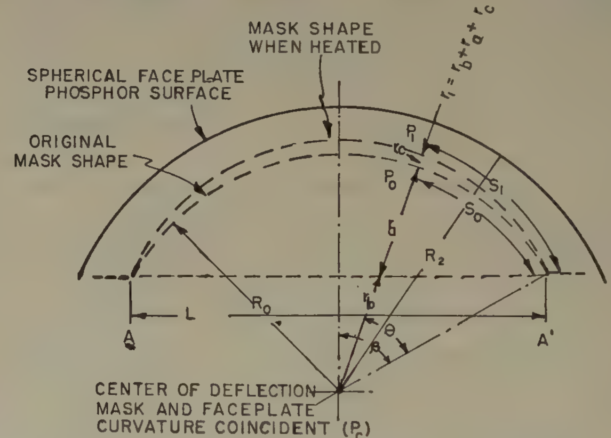


Fig. 9—Geometric relationship of spherical mask and spherical face plate.

Appendix

This section derives an approximate expression for the behavior of the spherical mask when it is heated, as by beam bombardment during operation in a color tube.

Fig. 9 shows the schematic relationship between a spherical aperture mask and a spherical face plate. It is presumed, on the basis of Stoker's analysis, that the apertures in the mask will not materially alter its behavior.[6] As shown in the drawing, which is a sectional view produced by passing a plane through the geometric center, the face plate and the initial mask form are represented by circular arcs. The spherical symmetry of the figure permits two-dimensional analysis.

The mask is presumed to be supported in the region A and A' in such a manner that its center of curvature is coincident with that of the center of curvature of the

face plate. The active area (the region of the apertures) is restricted to the spherical portion. Initially, the rim, as designated at points A and A', is assumed to restrain corresponding points around the edge of the spherical portion so that they do not move with respect to the face plate.

The initial temperature is considered to be uniform and to have the value T_0 absolute. The mask is considered to have an initial spherical radius R_0, and the face plate is considered to have a radius R_2, a constant.

In this discussion, the symbol convention that upper case letters represent scalar quantities and the lower case letters represent vector quantities will be used.

A line connecting point P_c and A' is to be the reference line for angle θ. The heated surface of the mask is defined as a locus of a series of points P_1, which represent the terminii of vectors under the heading r_1, originating at P_c.

In the second condition, the mask is assumed to be uniformly bombarded with electrons so as to be raised to a temperature condition T_1 at the center. An approximate expression for r_1, based on the assumed similarity of behavior between spherical shells and spherical solid segments of one base is derived as follows: In Fig. 9:

$$r_1 = r_0 - r_o = r_b - r_a - r_c = r_0 - at(r_a)$$

where

$t = T_1 - T_0$

a = linear coefficient of thermal expansion of material of mask.

It is assumed that the vector r_1 passes through a point P_0 on the original spherical mask surface and terminates at point P_1, which is the position P_0 would occupy on the mask after heating from T_0 to T_1.

From Fig. 9:

$$\sin\beta = L/2R$$

$$\cos\beta = (R_0^2 - L^2/4R_0^2)^{1/2}/R_0$$

$$r_b = r_0 \cos\beta/\cos\theta$$

$$r_a = r_0 - r_b = r_0(1 - \cos\beta/\cos\theta)$$

$$r_1 = r_0[1 + at(1 - \cos\beta/\cos\theta)].$$

The expression for r_1 may be simplified to the form:

$r_1 = f + g \sec\theta$; if, $f = R_0(1 + at)$ and $g = -R_0 at \cos\beta$.

For given tube dimensions g and f may be constant. This is the general equation for the *Conchoid of Nicomedes.*

When the mask is of thin material and is supported in vacuum, the temperature T_1 is primarily a function of the radiation characteristics of the aperture mask and the surrounding medium. This condition is defined by the Stefan–Boltzmann equation:

$$q = \delta A(T_1^4 - T_0^4)/e \quad \text{where}$$

$$\delta = 5.71 \times 10^{-5} \text{ ergs/cm}^2 \text{ sec degree Kelvin.}$$

However, the heat conduction in the vicinity of the edge of the heated region is used to account for the discrepancy:

$$[r_0]\theta(1 + at) = S_0(1 + at) > \int_0^\theta [r_1^2 + (dr_1/d\theta)^2]^{1/2} d\theta.$$

The inequality indicates that T_1 does not represent precisely the temperature condition throughout the mask due to a uniform bombardment of electron beams. The condition is such that the shape described as the *Conchoid of Nicomedes* does not terminate abruptly at the edge, but blends as the result of the conducted heat. Because the material is thin, however, this "blending" occurs in a very small zonal area, and does not seriously affect registry.

Fig. 10 shows the geometry involved in a practical tube. To accomplish color discrimination, the beams originate from positions off the central axis of the tube. It will be noticed, also, that an area identified as localized heating shows qualitatively the effects anticipated. If the original assumptions made for the condition of the rim at AA' can be applied to a small heated area, the analysis used for total mask heating by electron beams can be used for small area heating. This would only require that the unheated portion of the mask did not move appreciably due to the effect of heat on a small portion. The assumption is consistent with the original proof that the convex surface is rigid.

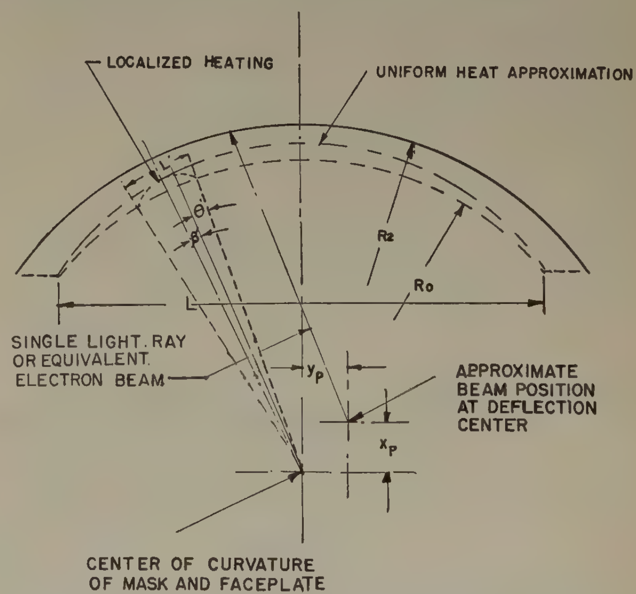


Fig. 10—Schematic representation of localized heating and over-all heating.

This condition of localized heating is described on the figure by the L', θ', and β' dimensions. These dimensions may be chosen at will to analyze any part of the shadow mask surface. However, it may be shown that the maximum misregistry occurs when $L' = L$; so this case is of greatest interest.

Fig. 11 shows the geometry of a spherical shadow mask, spherical face plate color tube. The picture shows an electron beam displaced by a horizontal distance x_p

and a vertical displacement y_p from the reference axis and origin. The section chosen in Fig. 11 is selected at such a position that the maximum possible misregistry will occur. That is where $\alpha+\beta$ is a maximum.

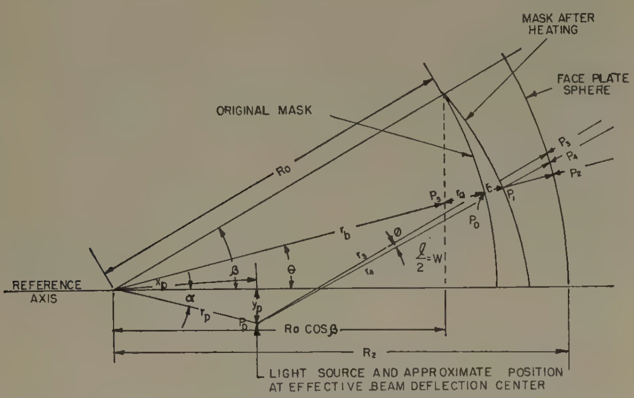


Fig. 11—Simplified geometry for analysis of effect of heating on registry.

Here as in other portions of the analysis, it is assumed that the electron beams travel in straight lines. As before, the original mask radius is given as R_0, the face plate radius as R_2, and the heated mask surface is described by vector r_1. P_0 represents a point on the original mask surface, and P_1 represents the same point on an expanded mask surface. r_4 and r_5 are considered as electron beams traveling through P_1 and P_0 and terminating at P_4 and P_3 on the phosphor or face plate respectively. They are separated by an angle ϕ. The distance between points P_3 and P_4 is considered as the amount of misregistry, and is a function of ϕ. Using the approximation derived for the shape of the heated surface, the expression for the misregistry M, may be shown to be:

$$M=[r_p]R_0\frac{at(\cos\theta\cos\beta)(\tan\theta\cos\alpha-\sin\alpha)}{R_0^2[r_p]^2-2[r_p](\cos\theta\cos\alpha-\sin\theta\sin\alpha)}$$

where

$$[r_p]=\sqrt{x_p^2+y_p^2}.$$

Using the following parameters,

$R_0=21.5''$
$R_2=22.0''$
$a=15.6\times10^{-5}/°C$
$L=12.0''$
$X_p=4.5''$
$y_p=0.290''$
$t=100°$ (representing approximately 50 watts incident on screen)
$\delta=$emissivity factor of 0.7″ was used. (All masks used had black "satin" surfaces)

the calculated values of the misregistry at various angles of deflection are:

TABLE I

θ (Deflection) degrees	(Numerical misregistry) $\times10^{-6}$ inches
16.2 (β)	0
12	27
8	54
6	51.8
4	44.7
0	22.8
α	0

As pointed out in an earlier section, this result is confirmed by experiment.

ACKNOWLEDGMENT

The authors wish to extend special recognition to Messrs. T. Hodge, P. Librizzi, Dr. P. N. Hambleton, and other members of the Color Development group of CBS-Hytron, for the long hours and hard work they have put into materializing the CBS-Colortron.

A Laboratory Receiver for Study of the NTSC Color Television System*

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Summary—**The paper describes in detail, with suitable block and circuit diagrams, the operation of a laboratory color television receiver fulfilling the present NTSC standards.**

The receiver consists of the video signal source and monochrome monitor, the color decoder system, the color synchronization system, local subcarrier oscillator, the horizontal and vertical deflection system, the high voltage (second anode and focus) and convergence system, and the tricolor tube's mount. Also, an additional color decoder is described which will permit the operation of color slave units in addition to the main color receiver.

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I. INTRODUCTION

During the past few years, considerable attention has been given to the development of a compatible color television system. Specifications for such a system have been established by the NTSC. The color receiver to be described is a laboratory model which conforms with these specifications and was designed to permit:

1. High flexibility for circuit changes and adjustments required to test and study the performance of various components (especially new tube types) and circuits; and

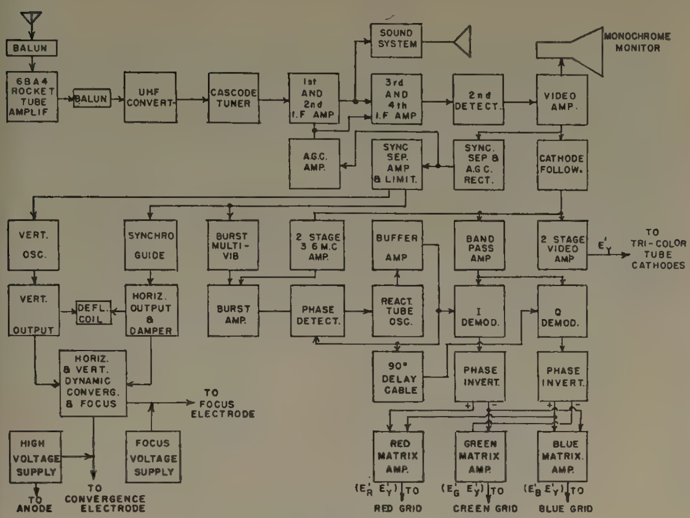

Fig. 1—Block diagram of color receiver.

2. A direct comparison of a monochrome signal, either vhf or uhf, displayed on both a black-and-white picture tube and an RCA tricolor tube.

II. NTSC Standards

Due to the nature of the NTSC color television signal, certain requirements must be fulfilled in the design of a color television receiver. The NTSC type of color transmission consists of the normal monochrome television signal (luminance, synchronization, and sound signals) to which color information has been added. This added information consists of a modulated color subcarrier, referred to as the chrominance signal, and a color synchronization signal (3.579545 mc) which supplies a phase reference for the chrominance signal. The color television signal established by the NTSC has the following composition:

$$E_M = E_Q' + E_Q' \sin (wt + 33°) + E_I' \cos (wt + 33°)$$

where:

$$E_Y' = 0.41(E_B' - E_Y') + 0.48(E_R' - E_Y')$$

$$E_I' = -0.27(E_B' - E_Y') + 0.74(E_R' - E_Y')$$

$$E_Y' = 0.30E_R' + 0.59E_G' + 0.11E_B'.$$

For color difference frequencies below 500 kc, the signal can be represented by:

$$E_M = E_Q' + \{.88[.56(E_B' - E_Y') \sin wt + (E_R' - E_Y') \cos wt]\}.$$

The phase reference of the color synchronization signal called the burst signal, is sin $(wt+180°)$.

In these expressions, the symbols have the following significance:

1. E_M is the total video voltage.
2. E_Y' is the gamma-corrected voltage of the monochrome (black-and-white) portion of the color picture signal.
3. The expression in { } is the gamma-corrected voltage of the chrominance signal.

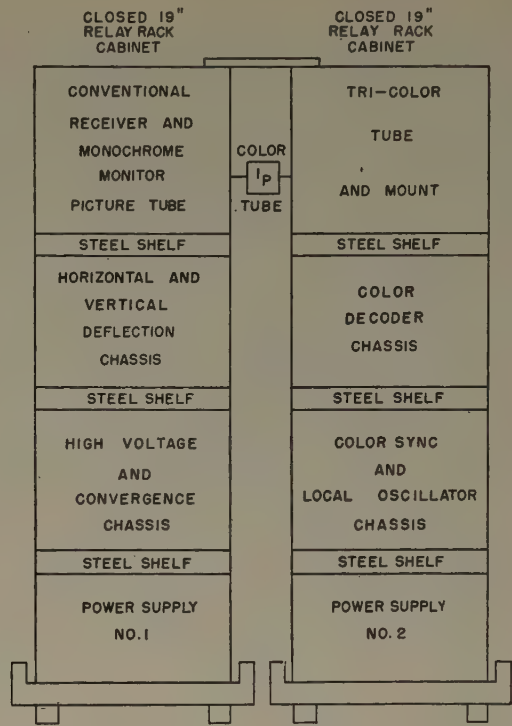

Fig. 2—Physical layout of color receiver.

4. E_Q' and E_I' are the two gamma-corrected orthogonal components of the chrominance subcarrier corresponding respectively, to the narrow-band and wide-band signals.
5. E_R', E_G' and E_B' are the gamma-corrected voltages corresponding to the red, green and blue signals.

III. Receiver Requirements

It is apparent that, in addition to the needs of the conventional television receiver, the nature of the color television signal establishes the requirements for the design of a color television receiver. They are as follows:

1. A monochrome channel for the black and white presentation.
2. A bandpass circuit to extract the chrominance signal from the total video signal.
3. A local color oscillator and demodulators to extract the E_Q' and E_I' signals from the chrominance signal.
4. Matrix amplifiers to combine the correct proportions of E_Q', E_I' and E_Y' to obtain the color or color difference signals (whichever is desired) to be applied to the tricolor tube.
5. Horizontal and vertical deflection circuits for the tricolor picture tube.
6. Regulated dc potentials for second anode, convergence and focus electrodes of tricolor tube.
7. Dynamic convergence and focus signals.
8. Regulated low-voltage power supplies.

IV. The Color Receiver

A block diagram of the receiver is shown in Fig. 1, and the physical layout is shown in Fig. 2.

A. Monochrome Monitor

In order to detect the transmitted television signals, a conventional monochrome receiver is used. Some of the features of the receiver are: a turret cascode tuner, a double tuned bandpass type 25 mc intermediate frequency amplifier, a germanium crystal diode second detector, and a 4 mc bandwidth video amplifier. In order to receive the color transmissions, the following modifications were made:

1. The tuner was realigned to favor channels 4, 5 and 6 since these channels are normally used to receive the color signals in the New York area at this time. It should be noted that most tuners are aligned for a compromise for all 12 vhf channels.
2. The IF amplifier was realigned to increase the bandwidth to about 4.2 mc. To insure proper overall alignment and error-free results due to the injection of an IF sweep signal at the mixer, an RF sweep signal, tuned to channel 4 in conjunction with RF markers, was applied to the antenna input. Fig. 3 is the response curve obtained at the second detector.

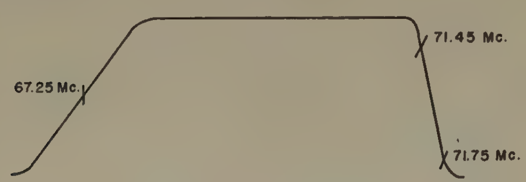

Fig. 3—Receiver over-all response characteristic.

3. The video amplifier circuit was redesigned to give a bandwidth of 4.2 mc to insure the passage of all the color information. A cathode follower using a type 6J6 tube is used to couple the video signal to the low impedance cable which delivers the video signal to the decoder chassis.
4. Additional connectors, with resistance-capacitance isolation, were provided to deliver the horizontal and vertical synchronizing pulses to the deflection, convergence and decoder chassis.
5. The internal low voltage supply was disconnected and replaced by an external regulated power supply. The original filament supply was left intact.

A dual uhf corner reflector was used to receive the experimental DuMont uhf (channel 54) color transmissions. The transmitter is located ten miles from our laboratory. A rocket tube (6BA4) was used to amplify the signal which was converted to channel 6 by means of a commercial uhf converter. Baluns were used on either side of the rocket tube amplifier in order to match the balanced 300 ohm transmission lines as shown in Fig. 1.

B. Tricolor Picture Tube Mount

The mount for the tricolor tube is fairly complex due to the fact that the tube has a metal cone and is somewhat heavy. The metal cone requires very good insulation since the tube is operated at a second anode (cone) voltage of 20 kv. A polyethylene cone, lip ring and lucite support mounts were used to prevent arcing and corona. It should be noted that bakelite cannot be used for the insulating support mounts since a leakage current of 50 microamperes resulted when it was used. In addition, the color tube socket has to be further insulated with sleeves of polyethylene on pins 9 and 10 to prevent arcing. The tube's weight necessitates a sturdy frame for support; therefore, one inch aluminum angles were used. A side view sketch of the mount is shown in Fig. 4.

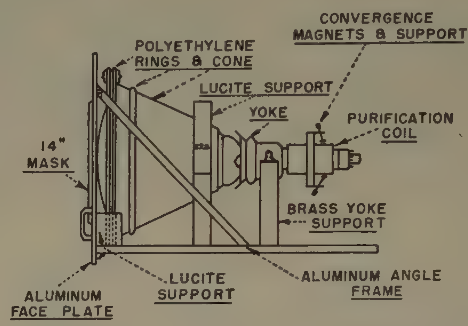

Fig. 4—Side view sketch of the color tube mount.

C. Deflection Circuits

The horizontal and vertical deflection circuits (Fig. 5) were designed to permit good control of the horizontal and the vertical size, linearity and synchronization of

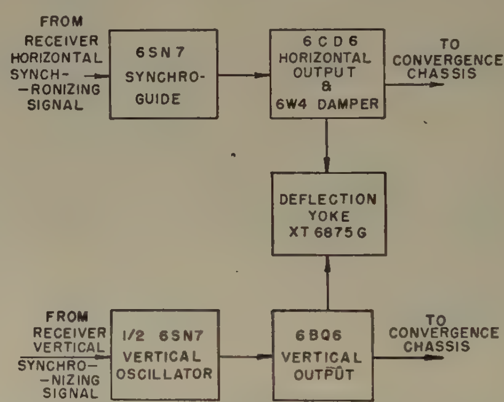

Fig. 5—Block diagram of the horizontal and vertical deflection circuits.

the picture on the face of the tricolor tube. The horizontal and vertical deflection circuits are completely isolated from each other physically, as well as electrically, as can be seen from layout shown in Fig. 6.

The only point where they run side by side is from the deflection chassis to the yoke and here the vertical leads are shielded. The reason for this is to prevent the vertical interlace from being effected by the horizontal pulses.

The horizontal sawtooth is obtained from a conventional synchro-guide type circuit employing 1/2 6SN7 as the horizontal oscillator and discharge tube and 1/2 6SN7 as the afc tube. The output circuit employing a 6CD6G as the horizontal output amplifier is conventional in form but requires specially designed output transformer (RCA XT6820J) and deflection yoke; since, although the horizontal deflection angle is only 45 degrees, the tube neck diameter is approximately

that of normal picture tubes. This larger diameter neck requires more deflection power, a change in yoke design and a change in transformer design to match the yoke to the output tube. Due to the need for a regulated high voltage supply to permit registration of the tricolor tube, the kickback voltage developed in the horizontal output circuit is not used in this design. Therefore, the high voltage winding is eliminated from the output transformer, thus permitting a more efficient deflection system. Horizontal centering is obtained by a change of dc current flowing through the horizontal deflection coils.

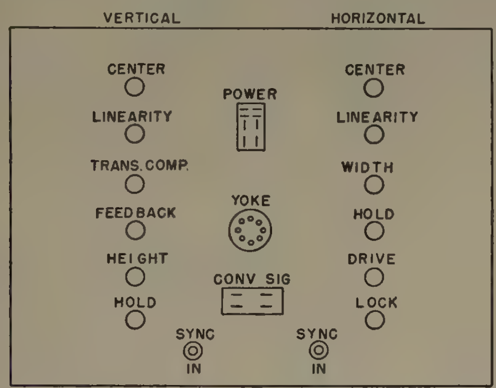

Fig. 6—Physical layout of the horizontal and vertical deflection chassis.

Vertical deflection is obtained by use of a stabilized vertical deflection system employing inverse feedback. 1/2 of a 6SN7 is the vertical oscillator and a 6BQ6 is used as the output tube. The inverse feedback coupling capacitor and resistor are part of the sawtooth generating circuit, and the blocking oscillator tube is intimately associated with them. This circuit permits improved over-all operation since the vertical height and linearity will not change with time, ambient temperature or aging of the output tube. Vertical centering is obtained by electrical means, that is, a change of dc current flowing through the vertical deflection coils.

D. Dynamic Convergence and Focus

Due to the construction of the RCA tube, dynamic focus and convergence adjustments are required for satisfactory operation. Since the aperture mask and the phosphor-dot screen are flat, the beam-path length from the electron gun focusing and converging lenses to the mask is a function of the position of the phosphor dot being scanned. The path is the shortest at the center of the aperture mask and the longest at the edges. This means that the focal length of the electron gun focusing and converging lenses must be made to vary as a function of the position of the dot being scanned. Dynamic focusing and convergence is accomplished by applying a voltage, derived from the horizontal and vertical deflection circuits, to the electron gun focus and convergence electrodes so as to vary their dc potentials in an approximately parabolic manner.

In addition to the dynamic focusing and convergence adjustments, a color purifying coil and beam positioning magnets are required to achieve proper convergence of the three beams. The color purifying coil is located on the neck of the tricolor tube. It is used to adjust the position of the common axis of the electron beams so that, when deflected, they approach each hole in the aperture mask at the proper angle to strike the appropriate color phosphor dots. The current through the coil determines the *magnitude* of change in beam position, while the rotational orientation of the coil determines the *direction* of the change in beam position.

The beam positioning magnets consist of three permanent magnets placed over each gun. Their adjustment aids in achieving proper convergence of the beams by correcting for (a) slight dissymmetries caused by manufacturing variations in the tube and (b) the effect of stray fields which may be present.

If proper convergence near the edges cannot be attained with these controls, it is an indication that some distortion is present in the deflection yoke. To correct for these minor distortions, yoke field-compensating tabs are used. Two tabs usually furnish adequate correction.

The horizontal-dynamic-convergence amplifier (Fig. 7) uses a type 5763 tube. The input, which is parabolic in shape, is taken from the cathode circuit of the horizontal output tube and applied through a gain control to the grid of the horizontal dynamic convergence amplifier. The output, which should be approximately parabolic in wave form, is applied to the primary of the horizontal-dynamic-convergence transformer and the primary of the horizontal-dynamic-focus transformer which are in parallel. These transformers are tuned to resonance, at the horizontal scanning frequency, by the horizontal-dynamic-convergence phasing coil. The phasing coil shifts slightly the phase of the convergence wave form with respect to the horizontal-scanning frequency. This may be necessary in order to obtain optimum convergence uniformity. The phase shift may result in rounding off the sharp peaks of the parabolic wave form until it becomes almost sinusoidal in appearance but will not affect the color tube performance since the sharp peaks occur during horizontal blanking. The dynamic focus and convergence outputs are then superimposed on dc components (3 kv for the focus electrode and 9 kv for the convergence electrode) and applied to the focusing and convergence electrodes of the tricolor picture tube.

The vertical-dynamic-convergence amplifier (Fig. 7) is a two stage amplifier using a type 12AU7 tube. The input is taken from the cathode circuit of the vertical-output tube and applied through a gain control to the grid of the amplifier. The output, which should also be approximately parabolic in shape, is applied to the primaries of the vertical dynamic-convergence transformer and the vertical-dynamic-focus transformer which are in parallel. These voltages are then superimposed on the dc and horizontal components of the focus and convergence voltage and applied to the respective electrodes of the tricolor picture tube. Voltage wave forms and dc levels at the different points in the convergence chassis are also shown in Fig. 7, following page.

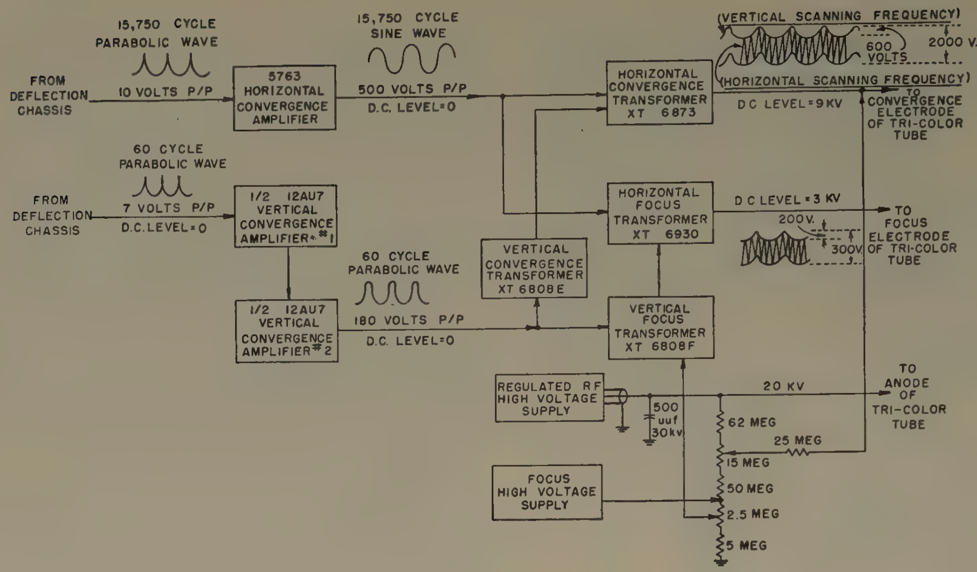

Fig. 7—Block diagram of the dynamic convergence and focus circuits.

E. High Voltage Sources

To permit the receiver to operate satisfactorily under all conditions of line voltage variations, it must be operated with all electronic regulated power supplies. Since the voltages at which the various elements of the tube are operated and the currents drawn are radically different from each other, separate regulated dc supplies are required. The tube is operated with the following regulated dc sources:

1. A low voltage supply to provide the grid bias and screen voltage.
2. A high voltage (3 kv at 0.5 ma) supply for the focusing electrode.
3. A high voltage (10 kv at 0 ma) supply for the convergence electrode.
4. A high voltage (19 kv at 0.5 ma) supply for the second anode electrode.

Of course, the deflection systems and the signal sources (color and black-and-white) are also operated from regulated power sources.

A conventional horizontal deflection system optimized for high voltage output is used for the second anode electrode. As can be seen in Fig. 8, a portion of the output voltage is fed into a three stage direct coupled amplifier operating from a regulated power supply. The negative dc output voltage of the amplifier is returned to the bottom end of the grid resistor of the horizontal output tube. Therefore, if for example, the high voltage should increase, the signal (+ voltage) fed into the dc amplifier will increase. The negative output of the dc amplifier will go further negative driving the horizontal output tube further towards cutoff and reducing its plate signal, which in turn holds the high voltage to a predetermined value.

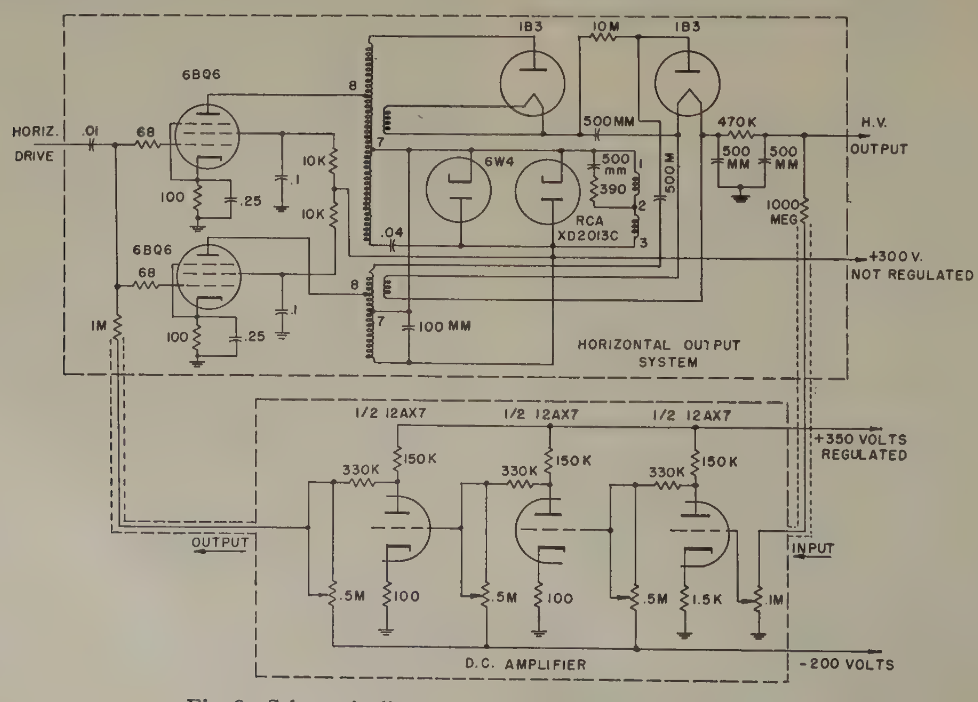

Fig. 8—Schematic diagram of a regulated high voltage source.

It is to be noted that the voltage source for the horizontal output system is unregulated. Regulation is not required since the dc amplifier will correct for any change in the system's performance.

The method of regulation has a safety feature which will cut off the second anode voltage if the horizontal deflection of the tricolor tube fails. This is a result of operating the high voltage unit and the color tube horizontal deflection system from the same horizontal drive voltage. The high voltage necessary for the convergence electrode is taken from a voltage divider network at the output of the second anode high voltage supply.

Focus electrode high voltage dc supply consists of a voltage doubler using two of the type 2X2A tubes (Fig. 9). The supply has a ripple of 0.1 per cent and a regulation of better than 0.1 per cent for load currents from 0 to 500 microamperes.

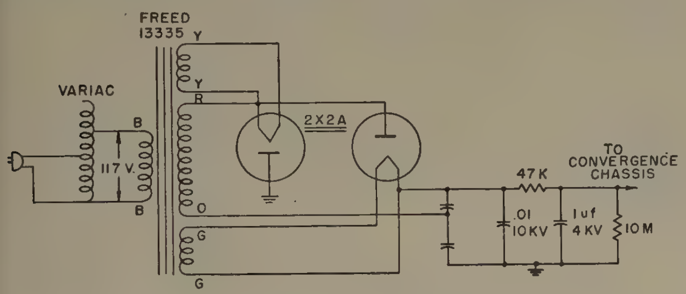

Fig. 9—Schematic diagram of the dc focus supply.

F. Low Voltage Sources

The low voltage supplies consist of two well regulated power supplies which are set at 350 v and capable of delivering 500 ma each.

G. Color Synchronization and Local Subcarrier Oscillator

The color synchronization signal is transmitted by means of a burst of unmodulated subcarrier (3.579545 mc) following the horizontal synchronizing pulse as shown in Fig. 10. This unmodulated subcarrier, referred to as the burst signal, consists of nine cycles of 3.579545

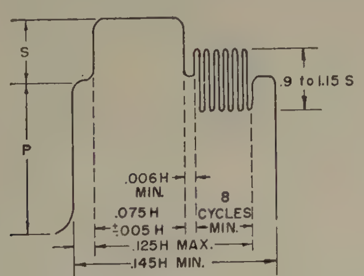

Fig. 10—The color synchronization signal.

mc at a phase reference of 180 degrees to the blue difference signal. It is used to establish a cw reference signal of the same frequency and related phase for application to the synchronous demodulators which extract the I and Q components out of the chrominance signal.

It can be seen from Fig. 10 that the burst lasts for only a small part of the total time (0.4 per cent); therefore, the complete sync signal should be gated to exclude any signal which may occur when there is no burst. To accomplish this, a burst multivibrator (12AU7) is used (Fig. 11). The frequency of the multivibrator is the same as the horizontal scanning frequency. The positive output pulse is at least as wide as the burst but not wide enough to include any video signal since the video chrominance component can introduce large phase errors due to its high amplitude.

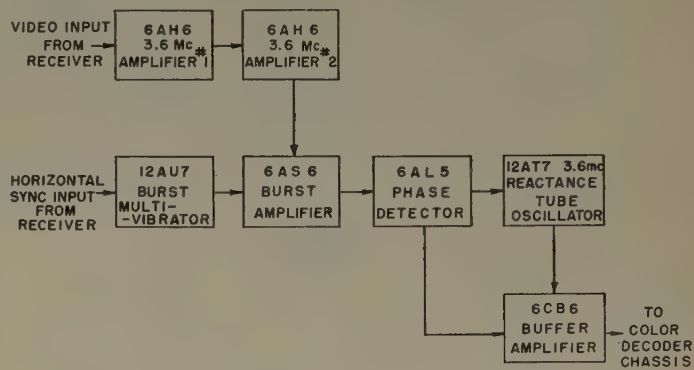

Fig. 11—Block diagram of the color oscillator chassis.

The complete video signal is applied to a two stage (6AH6's) amplifier tuned to 3.6 mc. The purpose of this amplifier is to eliminate all signals but the color subcarrier signals. This narrow band signal is then applied to the grid of a 6AS6 gated (burst) amplifier. This stage is gated by the output of the burst multivibrator which is applied to the 6AS6 suppressor.

One of the aims of this receiver is to test the performance of various components and circuits for use in color television sets. As a means toward this end, a type 12BY7 tube was used in place of a type 6AS6 tube as the burst amplifier. It was found that the 12BY7 gave a "cleaner" output wave form than the 6AS6, but at a reduced level under the same operating conditions. As a result of the "cleaner" wave form, the 12BY7 was able to keep the local color oscillator in phase and frequency lock at all times.

The output from the burst amplifier is then applied to integrating circuits which convert the burst to the cw color reference signal. The type of integrater used in this circuit depends on the automatic-phase control of a locally generated oscillation. The apc loop consists of a phase detector (type 6AL5 tube), a frequency selective filter which determines the loop response, a reactance tube (1/2 12AT7) and a local oscillator (1/2 12AT7). The oscillator has a good short-term stability but tends to drift after a few hours which is relatively unimportant for the type of data required from the receiver.

The oscillator's cw output is then applied to a 6CB6 buffer amplifier. The output from the buffer is applied to the color demodulators, located in the decoder chassis, after suitable phase splitting to obtain the desired and necessary quadrature relation.

H. Color and Monochrome Channels

The decoder chassis consists of a monochrome channel and a color channel. The monochrome channel consists

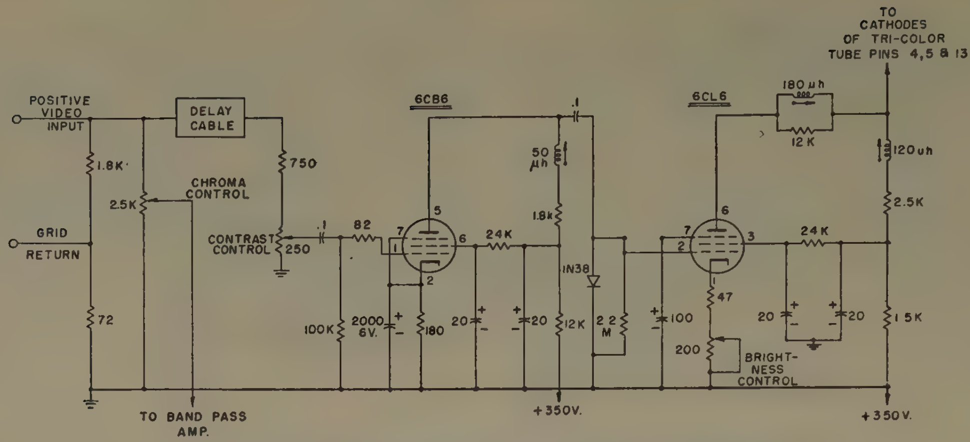

Fig. 12—(a) Schematic diagram of the luminance channel.

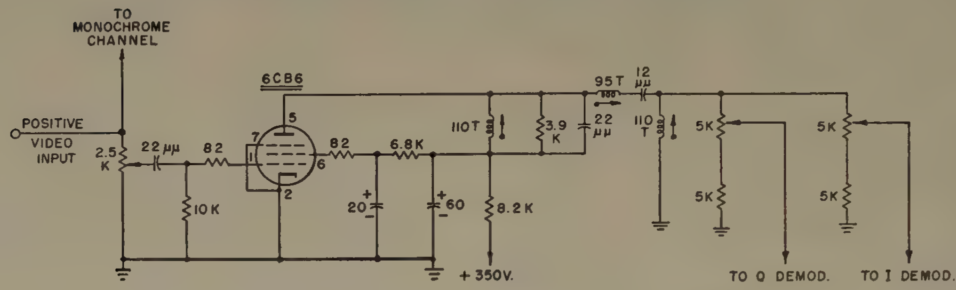

Fig. 12—(b) Schematic diagram of the band-pass amplifier.

of two video-amplifiers in cascade, one using a type 6CB6 tube and the other type 6CL6 tube. The over-all brightness is controlled by a potentiometer in the cathode circuit of the final stage while the contrast is controlled by varying the video input to the first stage. In order to have perfect coincidence of the monochrome and chrominance information at the tricolor picture tube, a 0.6 μsec delay cable is inserted in the mono-

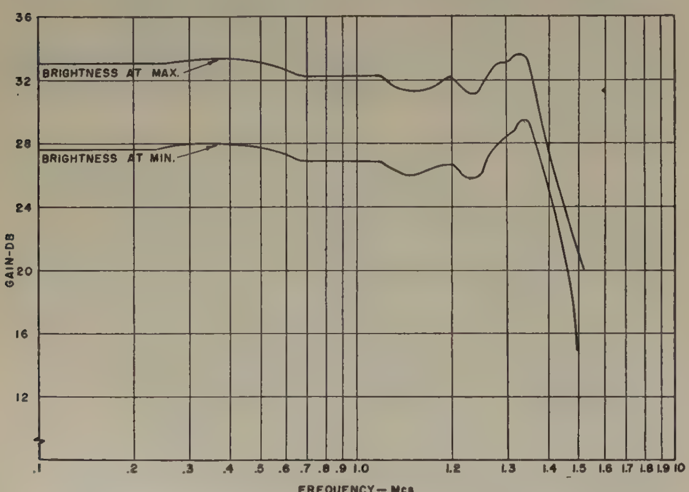

Fig. 13—Frequency response of luminance channel.

chrome channel. Eighteen feet of *RG* 65 *A/U* cable was used to obtain the required delay with good frequency response. Fig. 12a is a schematic diagram of the monochrome channel and Fig. 13 is its over-all frequency response with the *RG* 65 *A/U* delay cable.

The color channel employs a 6CB6 as a band-pass amplifier which has a pass-band of 2.2 mc (Fig. 14) centered about 3.3 mc. This response is needed in order to extract the chrominance signal which is a modulated subcarrier at 3.579545 mc. Fig. 12b is a schematic diagram of the bandpass amplifier.

The next step in recovering the color-difference signals is to extract the I and Q components from the chrominance signal. The I and Q components are recovered by two synchronous demodulators. A synchronous demodulator makes use of the principle of

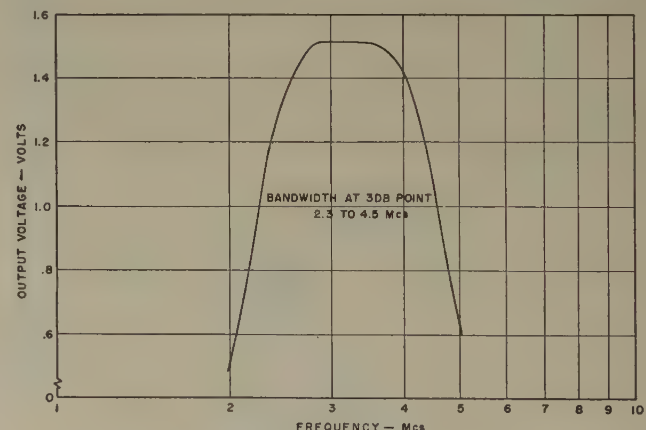

Fig. 14—Frequency response of band-pass amplifier.

zero-beat heterodyning in combining two signals to obtain a third. An input signal $E_{(t)}$ sin wt is applied to one of the control grids of the 6AS6 type tube and a second signal sin $(wt+\phi)$, having the same frequency but different phase, is applied to the other grid. The plate current is then proportional to the product of the two voltages and is

$$I_P = KE_{(t)} \sin wt \sin (wt + \phi)$$

which may be written

$$I_P = KE_{(t)} 1/2 \cos \phi - 1/2 \cos (2wt + \phi).$$

To eliminate the double frequency term, a low pass filter is placed in the plate circuit of the demodulator and the result is

$$I_P = \frac{KE_{(t)} \cos \phi}{2}.$$

Therefore, the output from the demodulator is proportional to the input-signal amplitude multiplied by the cosine of the phase angle (ϕ) between the color subcarrier and the heterodyning (reference) signal. Due to the nature of the color television signal, it can be seen that there are two methods of recovering the color difference signals. One method will not contain as much detail as the other. This will be discussed first.

If the low pass filter in the outputs of both the I and Q demodulators were tuned to pass only frequencies up to 500 kc, then the only part of the chrominance signal which would concern us would be

$$.88[.56(E_B' - E_Y') \sin wt + (E_R' - E_Y') \cos wt].$$

Now if the heterodyning (reference) signal were $B \sin wt$ (which means that it is 180 degrees out of phase with respect to the burst signal), then the output from the I demodulator would be

$$K_1 B \sin wt\{.88[.56(E_B' - E_Y') \sin wt + (E_R' - E_Y') \cos wt]\},$$

which expands into

$$.88K_1B\{.56(E_B' - E_Y')[1/2 \cos 0° - 1/2 \cos 2wt] + (E_R - E_Y)[1/2 \sin 0° + 1/2 \sin 2wt]\}.$$

Due to the band-pass characteristic of the output, the second and fourth terms are eliminated and the resultant output is

$$.246K_1B(E_B' - E_Y'),$$

which is the blue difference signal.

To obtain the red difference signal, the heterodyning (reference) signal is delayed by 90 degrees and applied to the Q demodulator. The resultant output would then be

$$K_2B \sin (wt - 90°)\{.88[.56(E_B' - E_Y') \sin wt + (E_R' - E_Y') \cos wt]\}$$

which expands into

$$.88K_2B\{.56(E_B' - E_Y')[1/2 \cos (-90°) - 1/2 \cos (2wt - 90°)] + (E_R' - E_Y')]1/2 \sin (-90°) + 1/2 \sin (2wt - 90°)]\}.$$

Due to the band-pass characteristic of the output, the second and fourth terms are again eliminated and the resultant output is

$$-.438K_2B(E_R' - E_Y').$$

Then due to the following relation

$$(E_G' - E_Y') = 0.51(E_R' - E_Y') + .19(E_B' - E_Y'),$$

the green color-difference signal may be obtained by correct matrixing of the I and Q outputs, being careful of the polarities. Fig. 15 is a block diagram of a color chassis using the above system.

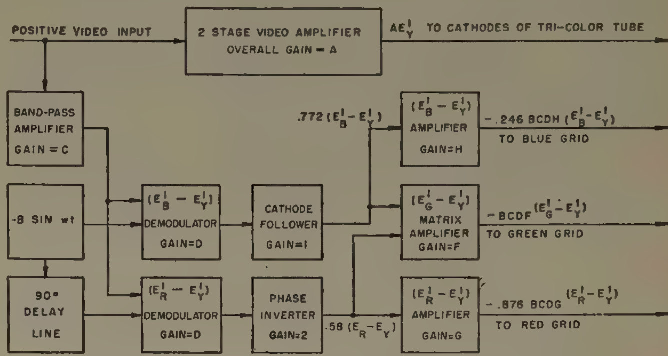

Fig. 15—Block diagram of a narrow band color decoder.

From the block diagram, it can be seen that the following is required:

$$.246H = .876G = F$$

and also that

$$.246BCDH = BCDF = .876BCDG = A$$

in order to have the three color voltages (E_B, E_G and E_R) present at the tricolor picture tube phosphor screen. Although this method gives the desired result, much detail is lost due to the narrow-band operation.

The synchronous demodulators to be discussed below, and which are used in the receiver, take into account the full bandwidth—namely, 1.3 mc for the I channel and 500 kc for the Q channel. With this bandwidth for the respective I and Q demodulators, the following results are obtained.

Assuming the heterodyning (reference) signal is

$$B \cos (wt + 33°),$$

then the output from the I demodulator will be

$$DB \cos (wt + 33°)\{-C[E_Q' \sin (wt + 33°) + E_I'(wt + 33°)] - .88C[.56(E_B' - E_Y') \sin wt + (E_R' - E_Y') \cos wt]\}.$$

D is gain of demodulator (including phase inverter) and C is gain of band-pass amplifier. A positive signal input to band-pass amplifier is assumed (see Fig. 1). Expanding and eliminating terms due to low pass characteristics of the demodulator gives a resultant output of

$$-DBC[.74(E_R' - E_Y') - .27(E_B' - E_Y')],$$

which can be written as

$$-DBCE_I'.$$

Since the Q channel demodulator bandwidth is 500 kc, the resultant output is

$$DB \cos (wt - 57°)\{.88C[.56(E_B' - E_Y') \sin wt + (E_R' - E_Y') \cos wt]\}.$$

Expanding and eliminating terms as before gives an output of

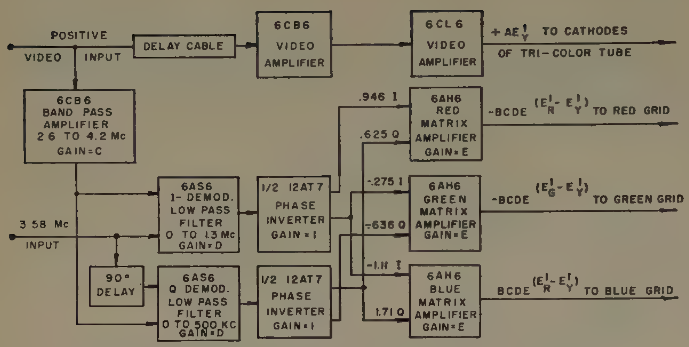

Fig. 16—Block diagram of a wide band color decoder.

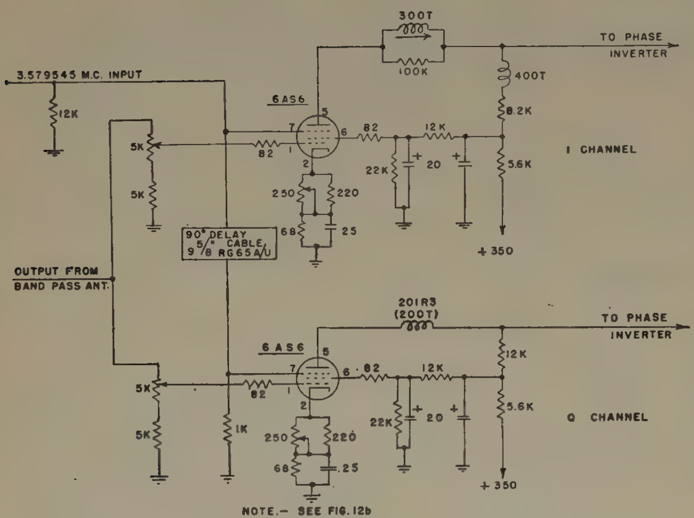

Fig. 17—Schematic diagram of the I and Q demodulators.

$$-\frac{DBC}{2}\left[.41(E_B' - E_Y') + .48(E_R' - E_Y')\right]$$

which can be written as

$$-\frac{DBC}{2} E_Q'.$$

Fig. 16 is a block diagram using the above system. Fig. 17 is a schematic diagram of the I and Q demodulators which were designed to have equal gains. Figs. 18 and 19 are frequency response characteristics of I and Q demodulators, respectively.

Now that the I and Q components of the chrominance signal have been obtained, a correct combination of the components is required to obtain the proper color difference signals. This is accomplished by means of matrix amplifiers using 6AH6 type tubes. The gains of all three color difference amplifiers are the same (gain $=E$). Table 1 tabulates the correct gain ratios of the I and Q components necessary to obtain the correct color difference signals. The feedback networks shown in Fig. 20 are required to maintain the gain ratios listed in Table I at right.

In order to obtain the correct polarity of the I and Q components, phase inverters were designed having equal output from either the cathode or plate. Fig. 20 is a schematic diagram of the phase inverters and matrix amplifiers.

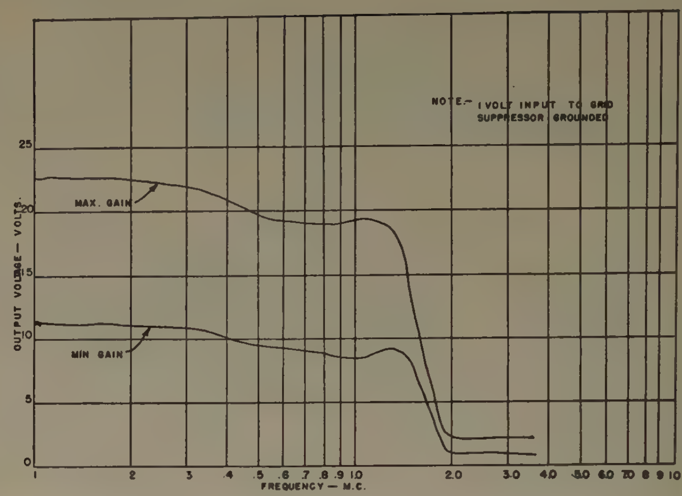

Fig. 18—Frequency response of the I demodulators.

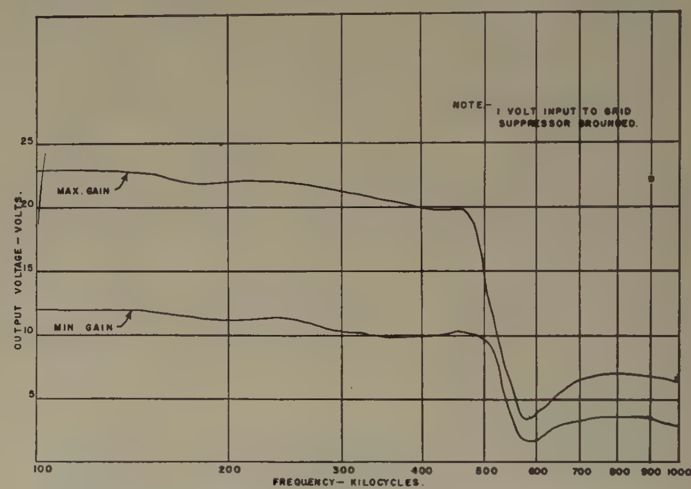

Fig. 19—Frequency response of the Q demodulators.

If the over-all gain of the monochrome channel is A (see Fig. 16), and D, C and E are the gains of the chrominance stages, then it can be seen that A must equal $DBCE$ in order to obtain the red, green, and blue signals at the tricolor picture tube phosphor screen.

TABLE I

Color Difference Signal	Gain Ratio for Q Components E_Q	Gain Ratio for I Components E_I
$(E_R'-E_Y')$	.625	.925
$(E_B'-E_Y')$	1.71	−1.11
$(E_G'-E_Y')$	.636	− .275

I. Slave Color Decoder Chassis

Since the receiver was designed to be as versatile as possible, an additional color decoder chassis was constructed to obtain the color signals E_R', E_G' and E_B'. This is accomplished by matrixing the color difference

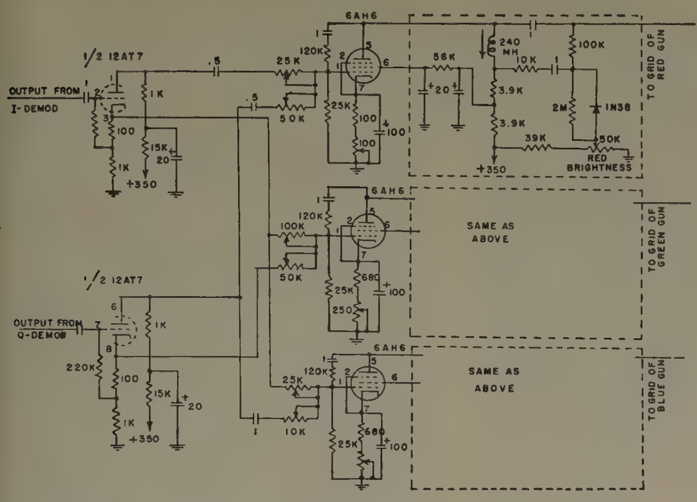

Fig. 20—Schematic diagram of the phase inverters and matrix amplifiers.

signals $(E_R'-E_Y')$, $(E_G'-E_Y')$ and $(E_B'-E_Y')$ with the monochrome signal, E_Y', in a manner similar to that described above. One disadvantage of this type of operation is that the matrix amplifiers and the final color video amplifiers require a 4.2 mc bandwidth, while the color difference decoder requires only a 1.3 mc bandwidth. As shown in Fig. 21 cathode followers are used in order to have complete isolation between the two decoder chassis and to eliminate any intercoupling between the color difference signals and the monochrome signals. A low impedance output is obtained by the use of additional cathode followers. The magnitude of the red, green, and blue outputs is 1 v peak to peak into 75 ohms. This design makes possible the operation of color slave units in addition to the main color receiver.

V. Conclusion

The color television receiver, described above, was designed for laboratory tests and, therefore, made as versatile as possible. The equipment permits the checking and detail study of many modes of operating a color receiver. All work was done using transmitted signals, from NBC and DuMont on vhf when available and from DuMont's uhf transmitter (708–714 mc).

When both vhf and uhf signals are available at the same time, it is possible to switch from one band to the other and, with no adjustments, the receiver will color lock within two seconds. Operation on both vhf and uhf was excellent.

VI. Acknowledgment

The authors wish to acknowledge the assistance of Patsy Albanese and George O'Hare, of the Physics Laboratories, in the construction of the receiver, and also to the DuMont Television Network for their co-operation in transmitting the vhf and uhf signals for the purpose of testing the receiver.

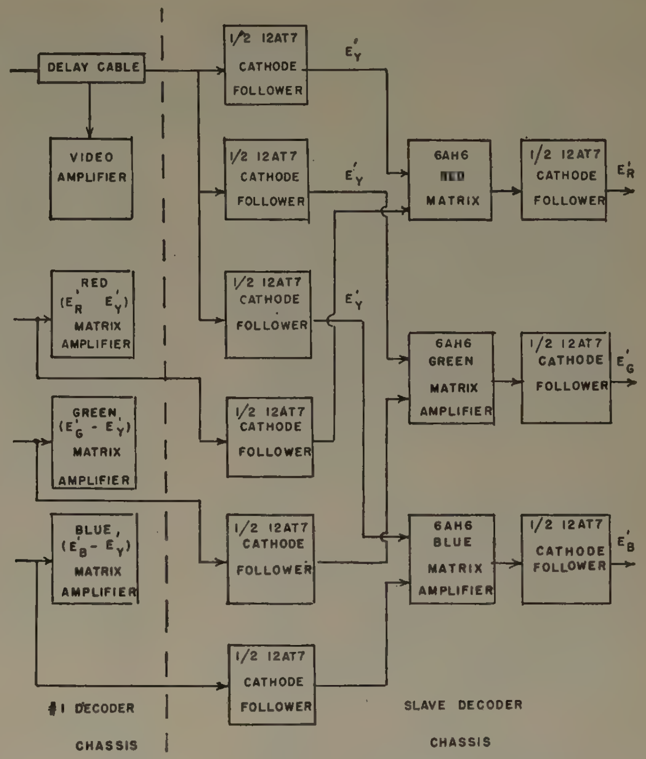

Fig. 21—Block diagram of a slave color decoder.

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For convenience of reference, there are listed below in chronological order the titles, authors, publications, and summaries of all papers published by the IRE on the subject of Color Television, with the exception of papers appearing in the present issue and in the first Color Television Issue of PROCEEDINGS in October, 1951.

—*The Administrative Editor*

Color Television—Part I—P. C. Goldmark, J. N. Dyer, E. R. Piore, and J. M. Hollywood. (PROC. I.R.E., vol. 30, pp. 162–182; April, 1942.) A brief history of color television and the reasons leading up to the Columbia Broadcasting System color television system have been presented. A general theory for color television, including color, flicker, and electrical characteristics, is also given. Equipment for color television transmission and reception has been designed and constructed based on these principles.

Postwar-Radio Planning—J. L. Fly. (PROC. I.R.E., vol. 31, pp. 33–35; January, 1943.)

Radio Progress During 1942—(PROC. I.R.E., vol. 31, pp. 127–132; April, 1943.)

Color Television—Part II—P. C. Goldmark, E. R. Piore, J. M. Hollywood, T. H Chambers, and J. J. Reeves. (PROC. I.R.E., vol. 31, pp. 465–478; September, 1943.) Part I of this paper included the fundamentals of the Columbia Broadcasting System color television system and the general application of colorimetry to color television. The equipment used in this color method was described. Part II deals with improved receiver-tube phosphors and the attendant changes in transmitter color characteristics. The color reproduction theory is extended to include changes in gamma and the action of the color mixer. An automatic color-phasing system is described. Sixty-cycle interference in viewing tubes and its prevention are reported as investigated. Work on the problem of increasing definition of color television by use of wider frequency band is described, and some considerations of certain possibilities of large-screen color television pictures are given.

Radio Progress During 1943—(PROC. I.R.E., vol. 32, pp. 124–130; March, 1944.)

Television Broadcast Coverage—A. B. DuMont and T. T. Goldsmith, Jr. (PROC. I.R.E., vol. 32, pp. 192–205; April, 1944.) An extensive field survey has been made of the three television transmitters in the New York City territory. The survey consisted of observations of many receivers permanently installed in the metropolitan area and of observations made with special receiving equipment mounted aboard the cruiser *Hurricane II*. Continuous recordings of field strength and still photographs have been made. This paper deals extensively with the multipath problem in television broadcasting which causes multiple patterns in the received picture. Extensive use is made of photographs and diagrams illustrating the appearance of these patterns and explaining the causes of these various types of "ghosts." The findings of this survey definitely lead to the conclusions that the lower-frequency channels provide the least multipath interference in metropolitan territory such as New York City. Reasonably good reception is found from all three New York Stations at distances beyond five miles up to the distances where signal level becomes too low for satisfactory receiver operation. Photographs are used to exhibit the quality of reception and types of programs now current in good locations around New York City.

Radio Progress During 1944—(PROC. I.R.E., vol. 33, pp. 143–155; March, 1945.)

Radio Progress During 1946—(PROC. I.R.E., vol. 35, pp. 399–425; April, 1947.)

An experimental Simultaneous Color Television System, Part I—Introduction—R. D. Kell. (PROC. I.R.E., vol. 35, pp. 861–862; September, 1947.) During 1945 and 1946 a complete sequential television system was constructed and tested. This was followed by the development of a simultaneous system, compatible with the present commercial monochrome television. This paper is the introduction to a group of two papers which describe the transmitting and receiving apparatus used in the simultaneous system.

Part II—Pickup Equipment—G. C. Sziklai, R. C. Ballard, and A. C. Schroeder. (PROC. I.R.E., vol. 35, pp. 862–870; September, 1947.) The technical development of the present flying-spot-type color television pickup equipment is described. The use of a high-voltage kinescope with a short persistence phosphor, of the multiplier-type photo-tubes and dichroic filters, permit the construction of apparatus for flying-spot scanning of color slides and color motion picture film providing excellent color video signals. The circuit equalization for the phosphor persistence is described in detail. The use of the simple flying-spot scanner for studio pickup is described.

Part III—Radio-Frequency and Reproducing Equipment—K. R. Wendt, G. L. Fredendall, and A. C. Curry. (PROC. I.R.E., vol. 35, pp. 871–875; September, 1947.) A new source consisting of a gas tube in a transverse magnetic field has been developed. Characteristics of the noise source are presented, together with some consideration of the problems in the amplification of noise. Typical noise-amplifier circuits are given for frequency bandwidths from 0.1 to 2.5 and 5 mc, respectively.

Radio Progress During 1947—(PROC. I.R.E., vol. 36, pp. 522–550; April, 1948.)

The Application of Projective Geometry to the Theory of Color Mixture—F. J. Bingley. (PROC. I.R.E., vol. 36, pp. 709–723; June, 1948.) Consideration is first accorded to the basic problem of the mixture of two colors of given luminosities. It is shown that a simple geometric construction will enable determination of the point on the chromaticity diagram corresponding to the mixture for any values of relative luminosities of the two component colors forming the ingredients of the mixture. The method is next expanded to consider the case of color reproduction by the amount of luminosity contributed to a color mixture by each of the three primary components are deduced and shown to be of simple type. Comparison of the results of choice of different sets of primaries is discussed and illustrated. The performance of equiluminous primary systems, such as have been proposed for sequential color television, is examined critically. The color-fidelity limitations inherent in such a system are demonstrated and discussed. The luminosity demands of each primary in a three-color television system are next examined, using the geometric method of analysis. For two given primary systems (those known as primaries *A* and primaries *C*, respectively), curves are shown indicating the contours of maximum luminosity demand of each primary when functioning in the reproduction of the full gamut of reproducible colors on the chromaticity diagram. It is shown that the maximum luminosity demand of any primary does not necessarily occur during the reproduction of white. As much as 41 per cent additional luminosity may be demanded of a given primary at a certain color as compared to its luminosity when reproducing white. In a television system, allowance must be made for this additional demand in the form of additional available undistorted voltage swing in the corresponding primary amplifier channel, if color distortion is to be avoided. The possibilities of the method of geometric analysis discussed are pointed out, not only with regard to its use for purely theoretical analysis with a simple, direct, and pictorial approach, but also as the basis for a wide range of graphical design methods which should be capable of wide application.

Spectral Power Distribution of Cathode-Ray Phosphors—R. M. Bowie and A. E. Martin. (PROC. I.R.E., vol. 36, pp. 1023–1029; August, 1948.) This paper embodies some of the results of a study undertaken because of the lack of substantial agreement among colorimetric determinations made from cathode-ray-tube screens by television manufacturers in the United States. The ICI (International Commission of Illumination) system of color specification is described, and is applied to the visible light produced by cathode-ray screens. A survey was made

of the principal colorimetric methods now in use by television manufacturers. These methods have been evaluated in terms of how closely their inherent characteristics meet the criteria of the 1931 ICI Standard Observer. The necessity for standardization of colorimetric measuring equipment is pointed out. Suggestions are offered as to the manner in which such standardization might be achieved.

Radio Progress During 1948—(Proc. I.R.E, vol. 37, pp. 286–321; March, 1949.)

Television—Why the Deep Freeze?—S. L. Bailey. (Proc. I.R.E., vol. 38, pp. 340–343; April, 1950.)

Reliability in Electronic Equipment—G. B. Devey. (Proc. I.R.E., vol. 38, pp. 344–345; April, 1950.) Since the last year of World War II, the use of electronic equipment has come more and more into being. Maintenance and repair techniques have so lagged behind this development that, in the case of military electronics, maintenance costs are sometimes one hundred times the production cost. Motivated by rising costs, the need for safety, and the lack of trained repair personnel, steps are being taken to provide greater reliability in electronic equipment. Using reliability data obtained from effective telephone repeater equipment and other systems, attempts are now being made to effect on-the-spot replacement of faulty subassemblies and to make available better vacuum tubes. Progress has been made with printed wiring components imbedded in plastic compounds. The military, faced with overburdening maintenance problems, production demands in times of mobilization, and untrained personnel, looks to development of greater reliability, inbred into equipment design. At present the military is seeking to have the manufacturer join, with comparable research, into the search for greater reliability. The Office of Naval Research is carrying out a research program in analyzing electronic maintenance minimization.

The Present Status of Color Television—(Proc. I.R.E., vol. 38, pp. 980–1003; September, 1950.) The Senate Advisory Committee on Color Television, under the Chairmanship of Dr. E. U. Condon, Director of the National Bureau of Standards and Senior Member of the IRE, has issued a comprehensive report on the principles, practices, and major factors involved in color television systems, together with an analytical study of various presently available color television systems (followed by appendices giving relevant and supporting technical data). The members of the above committee are S. L. Bailey, W. L. Everitt, D. G. Fink, and N. Smith.

Mixed Highs in Color Television—(Proc. I.R.E., vol. 38, pp. 1003–1009; September, 1950.) A high-quality color television system could be made by transmitting independent red, green, and blue images of equally high quality. The bandwidth required by this method would be three times as great as that required for a black-and-white picture of equal resolution and repetition rate, regardless of whether the images are transmitted in sequence or simultaneously. Tests made on the human eye, and reported herein, indicate that the acuity for detail residing in color differences is less than half as great as the acuity for detail residing in brightness. Therefore, if the brightness values in a color television system are transmitted with fidelity up to 4 mc, it is adequate to transmit the individual color values up to only 2 mc, with a corresponding saving in bandwidth. In the "mixed-highs" system described, each of the three color images uses frequencies from zero up to 2 mc and the "mixed highs," which carry only the brightness values of the fine detail, use a video frequency band from 2 to 4 mc. The total width of the video bands then is only 8 mc, instead of 12 which would be required for three identical bands from zero to 4 mc. The bandwidth saved by the mixed-highs technique is obtained not at the expense of picture quality, but is a legitimate saving that arises by avoiding the transmission of information which the eye is unable to use. In this sense the saving could be compared to that which occurs by transmitting only the visible spectrum of colors, omitting the ultraviolet which the eye cannot see.

The brightness acuity eye tests were made with projected charts without the use of television apparatus. A new-type test pattern was used having a calibrated blurred junction which corresponds to the light values resulting from the transient response of a video amplifier with restricted bandwidth in passing from a dark area to a light area. The measurement of acuity for detail in color was made with similar blurred junctions between areas of different colors. Though the work reported was done a number of years ago and was applied to the simultaneous system demonstrated by RCA Laboratories in 1946, the principles and techniques are equally applicable to the RCA color system demonstrated in 1949. In the latter system the mixed highs and the dot interlace jointly provide a three-to-one bandwidth reduction that allows a high-definition compatible color television service to be operated within the 6-mc radio-frequency channels now allocated for black-and-white television.

Television Broadcasting in the United States, 1927–1950—D. G. Fink. (Proc. I.R.E., vol. 39, pp. 116–123; February, 1951.)

Analysis of Synchronizing Systems for Dot-Interlaced Color Television—T. S. George. (Proc. I.R.E., vol. 39, pp. 124–131; February, 1951.) A mathematical analysis is made of two synchronizing systems which might be used in "dot" color televisions to synchronize the dotting or sampling frequency in the receiver. Synchronizing information is transmitted in bursts of carrier cohered in phase of approximately 3 mc during line fly-back time. The two systems analyzed are (1) a simple high-Q resonant filter and (2) an oscillator with automatic frequency control (afc). In order to maintain sufficient phase accuracy in the sampling frequency, crystal control of the transmitter is necessary. Since the variations of the frequency response of a particular crystal filter with variations of the frequency response of a particular crystal filter with time may be made essentially negligible, the problem resolves itself into calculating the parameters of the synchronizing system to keep below an acceptable value the random phase error due to noise together with the phase error caused by variations in frequency (static phase error) from crystal to crystal. Rather than attempt to minimize the sum of the random and static phase errors, the two have been dealt with separately because of their different character. A fundamental parameter in the calculations is the power carrier-to-noise ratio in the intermediate frequency, the carrier being measured at the sync tips. Calculations are made for values of this ratio of 1, 3, 5, this being considered the critical range. Results of the calculation show that when the phase error due to noise alone is fixed, the simple resonant filter and the afc with single time constant suffer the same static phase error. If phase errors single time constant suffer the same static phase error. If phase errors in the neighborhood 10 degrees can be tolerated, it appears then that receivers can be designed to operate without manual control of the dotting frequency down to carrier-to-noise ratios of about 2. This should be satisfactory since picture quality at this level is poor.

Radio Progress During 1950—(Proc. I.R.E., vol. 39, pp. 359–396; April, 1951.)

Quality of Color Reproduction—D. L. MacAdam (Proc. I.R.E., vol. 39, pp. 468–485; May, 1951.) The evaluation of quality of color reproduction poses many complex problems. Optimum reproduction needs to be identified. Since it depends upon the limitations of the reproduction process, as well as upon human vision and judgment, optimum reproduction will probably have to be determined for each process separately. The program is to vary the production controls in systematic manners, measure the resulting color reproduction in the best way known (e.g., the ICI method at the present time), submit the reproductions to visual judgments, and study the judgment data in comparison with the measurements in order to find significant correlations. The growing experience of such studies of color photography is suggested as a guide. Preliminary estimates of optimum reproduction and of seriousness of deviations may be based tentatively on results of studies of noticeability of color differences and on fragmentary results of studies of color photography. These estimates can be improved as various parts of the program are carried out.

Color Television Issue of Proceedings of the I.R.E., October, 1951.

Radio Progress During 1951—(Proc. I.R.E., vol. 40, pp. 388–439; April, 1952.)

Requisite Color Bandwidth for Simultaneous Color Television Systems—K. McIlwain. (Proc. I.R.E., vol. 40, pp. 909–912; August, 1952.) It has been known for many years that the visual acuity of the human eye for color differences is less than that for changes in brightness. It has been shown that this fact can be used to reduce the bandwidth required for simultaneous color television systems. The experiments reported here relate to psychophysical meas-

urements made by both skilled and lay observers to determine just how far this reduction can be carried without objectionable deterioration of the reproduction. It is shown that under the conditions tested, approximately 1 mc is sufficient for most color reproduction, provided 4 mc are available for brightness detail.

Elimination of Moire Effects in Tri-Color Kinescopes—E. G. Ramberg. (Proc. I.R.E., vol. 40, pp. 916–923; August, 1952.) Moire effects which may arise in aperture-mask tricolor kinescopes are spurious intensity variations in the picture in the nature of beat patterns between the scanning lines and the aperture array in the shadow mask. The visibility of these effects depends on the relative magnitudes of the scanning-line width, mask-aperture size, aperture spacing, and line separation, on the orientation of the scanning pattern relative to the mask, and, finally, on the picture content. For the narrow aperture spacing normally employed (e.g., 215,000 apertures in a rectangular picture area of 104 square inches or 195,000 apertures in the somewhat smaller area defined by the framing mask) and for the preferred orientation of the scanning pattern, however, the moire effects are negligible. They may become noticeable, in the form of dot or bar patterns, if the aperture spacing is increased or the orientation of the scanning pattern relative to the mask is changed. The variation in the line transmission of the mask indicates directly the degree to which the mask may distort transmitted intensity values. It increases with a reduction in the ratios of line width and aperture diameter to aperture spacing and with a departure from the preferred orientation of the scanning pattern relative to the mask. Again, for the preferred orientation and within the range of spot sizes required for optimum resolution, the variation in line transmission is negligible—1 per cent or less. Furthermore, since the increase in the variation in transmission with departure from the preferred orientation is quadratic, the picture quality is insensitive to small deviations from the optimum orientation.

Gamma Correction in Constant Luminance Color Television Systems—S. Applebaum. (Proc. I.R.E., vol. 40, pp. 1185–1195; October, 1952.) A theoretical study is made of the effects of precorrecting the red, green, and blue image co-ordinates to provide unity over-all gamma. The effect of gamma precorrection is presented with regard to (a) tone rendition on the compatible monochrome receiver, (b) maximum demand of subcarrier and composite signal, and (c) noise interference sensitivity.

Generation of NTSC Color Signals—J. F. Fisher. (Proc. I.R.E., vol. 41, pp. 338–343; March, 1953.) The generation of compatible color signals according to NTSC specifications is covered in this paper. The equation for the composite signal is stated in terms of voltages existing in the red, green, and blue channels, and methods of calculating and measuring the composite video signal produced by a synthetic color bar chart generator are given. The development of the signal from the channel outputs of a color flying-spot scanner is illustrated with block diagrams, and the performance of a number of units in the chain is described. The signal specifications described in this article were used by the NTSC for field testing during the latter part of 1951 and also during 1952. On the basis of these tests certain modifications of signal specifications were made in January, 1953. These are listed at the conclusion.

Standards on Television: Definitions of Color Terms, Part I, 1953—(Proc. I.R.E., vol. 41, pp. 344–347; March, 1953.)

General Color-Receiver Design Considerations—C. J. Hirsch and B. D. Loughlin. (Trans. I.R.E., PGBTR-2, pp. 1–15; March, 1953.)

Connection of UHF and Color Adapters to UHF Receivers—L. H. Horn. (Trans. I.R.E., PGBTR-2, pp. 17–21; March, 1953.)

Radio Progress During 1952—(Proc. I.R.E., vol. 41, pp. 452–507; April, 1953.)

Specifications for Field Test of NTSC Compatible Color Television—W. R. G. Baker. (Proc. I.R.E., vol. 41, pp. 666–667; May, 1953.)

Measurement and Control of the Color Characteristics of a Flying-Spot Color Signal Generator—R. C. Moore, J. F. Fisher, and J. B. Chatten. (Proc. I.R.E., vol. 41, pp. 730–733; June, 1953.) This paper describes the optical system and measuring techniques which were developed for a flying-spot color television signal generator with the features of excellent fidelity over the full range of physically realizable color, flexibility of adjustment, and adaptation for special tests.

Optimum Utilization of the Radio Frequency Channel for Color Television—R. D. Kell and A. C. Schroeder. (Trans. I.R.E., PGBTR-3, pp. 33–39; June, 1953.) To produce a simultaneous television image in color, three communication channels must be available. The first of these may be used to transmit the scene brightness, the second the degree of color saturation, and the third the hue or color. For compatibility the brightness is transmitted as amplitude modulation in the usual way. A subcarrier is introduced to carry the other two pieces of information as amplitude and phase modulations. The optimum loading of these two auxiliary communication channels is the major consideration of this paper.

A Four-Gun Tube for Color Television Receivers—J. L. Rehnick and C. H. Heuer. (Trans. I.R.E., PGBTR-3, pp. 40–46; June, 1953.) While most NTSC Color Television receivers built to date have used the three-gun tricolor tube, experimentation with other displays has continued. This paper discusses some aspects of a four-gun four-color tube of the aperture-mask type: possibility of minimizing the effect of convergence and other rather deficiencies of the three-gun tube, video circuitry, implications with respect to system amplitude linearity or gamma correction.

Transient Consideration in the NTSC Color System—B. S. Parmet and L. M. Kaminsky. (Trans. I.R.E., PGBTR-3, pp. 47–67; June, 1953.)

Electronics and the Engineer—D. Sarnoff. (Proc. I.R.E., vol. 41, pp. 836–838; July, 1953.)

Colorimetry in Color Television—F. J. Bingley. (Proc. I.R.E., vol. 41, pp. 838–851; July, 1953.) This paper considers the relations between the colorimetric quantities of the system and the electrical signals into which they are encoded for transmission. The type of system considered specifically is that in which the complete video signal comprises a monochrome component together with a color carrier, which collaborate to transmit all of the information necessary for a subjective reproduction of a colored scene. However, the colorimetric equations derived in the paper are quite general, and would apply to any system of color reproduction.

The PDF Chromatron—A single or Multi-Gun Tri-Color Cathode-Ray Tube—R. Dressler. (Proc. I.R.E., vol. 41, pp. 851–858; July, 1953.) Described in this paper is a single gun and three gun version of a simple color cathode-ray tube developed by Chromatic Television Laboratories, Inc., based on the ideas of Dr. Ernest O. Lawrence of the University of California. Both types utilize post deflection focusing (PDF) and acceleration as will be discussed in the body of this paper. The principles described are quite general and may be applied to other cathode-ray tube and camera tube designs. The single and three gun types discussed below will operate with any of the presently proposed color television transmission systems.

A Subjective Study of Color Synchronization Performance—M. I. Burgett, Jr. (Proc. I.R.E., vol. 41, pp. 979–983; August, 1953.) The NTSC color-synchronization signal is reviewed to determine its operational quality. A subjective testing system is then described which dissects various receiver functions such that the thermal-noise impairment in each function may be evaluated. Results of these subjective tests show that color-synchronization performance is completely adequate under conditions of thermal-noise interference. The tests also show that the limiting factors of performance are primarily those functions which are common to monochrome transmission.

Color Signal Demodulators—D. H. Pritchard and R. N. Rhodes. (Trans. I.R.E., PGBTR-4, pp. 1–22; October, 1953). This paper presents a discussion of the problems and techniques involved in the design and development of color television receiver demodulators. The basic concepts of a simultaneous subcarrier color system are described as relating to the receiver demodulator problem. The particular signal specifications for field testing as proposed by the National Television System Committee are included to the extent of their effects upon receiver demodulator design. The discussion is intended to provide at least a working knowledge of the demodulator techniques utilized to date in color television receivers, which form a background for future developments of improved techniques.

Color Synchronization in the NTSC Color Receiver—W. E. Good. (Trans. I.R.E., PGBTR-4, pp. 23–39; October, 1953.)

Color Television—A Primer on the NTSC System—W. Feingold. (Trans. I.R.E., PGBTR-4, pp. 30–37.)

Theory of Synchronization Applied to NTSC Color Television—D. Richman. (I.R.E. Convention Record, part 4, pp. 3–8; 1953.) This paper presents the results of an analytical evaluation of the performance capabilities of the system used in NTSC color television to synchronize the color-carrier reference signal. The color synch burst appears to contain far more timing and synchronizing information than is required, although previously used synch systems have been inefficient in using the information. Analysis begins with determination of the amount of integration required for phase stability. The properties and limitations of "standard" passive and locked (APC) integrators are discussed. Integration requirements limit pull-in performance. The basic principle for overcoming previous limitations and obtaining the upper limit of performance is explained, leading to a determination of the ultimate capabilities permitted by the NTSC color synch signals. Simple techniques and new sync systems for approaching this limit are presented, and discussed. The physical principles apply to synchronizing systems, generally.

Color Synchronization in the NTSC Color Television Receiver by means of the Crystal Filter—W. E. Good. (I.R.E. Convention Record, part 4, pp. 9–12; 1953.) The quartz crystal filter or ringing circuit shows promise as a color synchronizing system for the NTSC color television receiver. Its performance is comparable to the AFC type circuit and it responds in the passive fashion. A typical circuit is given, the design parameters are discussed and some of the difficulties are noted.

APC Color Sync for NTSC Color Television—D. Richman. (I.R.E. Convention Record, part 4, pp. 13–17; 1953.) This paper presents a description of the characteristics and capabilities of a "standard" automatic-phase-control system applied to NTSC color-carrier reference-phase synchronization. Following a discussion of in-sync performance characteristics, a physical description of the mechanism by which the system pulls into synch provides a background for the relations between frequency pull-in range and time, and the in-sync characteristics such as noise bandwidth. The system includes a nonlinear (sinusoidal) phase detector. An explanation of results of a mathematical analysis, presented graphically, emphasized the upper limits of performance and how they may be obtained. A numerical evaluation for NTSC color synch indicates over-all satisfactory performance with this APC system.

Transient Response in a Color Carrier Channel with Vestigial Side Band Transmission—J. S. S. Kerr. (I.R.E. Convention Record, part 4, pp. 18–23; 1953.) Two independent signals used to modulate a carrier in quadrature can be detected without crosstalk only if the transfer characteristic of the network through which the modulation passes fulfills certain conditions of symmetry. For vestigial sideband transmission as proposed for the transmission of chrominance information by the NTSC these conditions may not be fully met. In systems being considered by the NTSC, residual crosstalk is eliminated either by CPA or by video filtering. Several types of vestigial sideband transfer characteristics which are used in the transmission of chrominance information are analyzed and compared, both for minimum phase and linear phase. Their video in-phase and quadrature transfer characteristics are shown along with the transients which arise from a step input.

Transients in Color Television—P. W. Howells. (I.R.E. Convention Record, part 4, pp. 24–34; 1953.) A color television system transmits three independent signals, each of which specifies one of the three coordinates that determine the location of the reproduced color in a three-dimensional color space. When a color transient occurs, each of these signals responds in a different manner determined by the characteristics of its own channel. The system response may be characterized by the resulting path along which the reproduced color point moves through the color space from its initial to its final location. The shape of such color transient paths is determined by the individual transient responses of the three channels as analyzed, and the subjective appearance of different transient-path shapes is discussed. Various modifications of the NTSC proposals are compared by these methods.

Colorimetric Properties of Gamma-Corrected Color Television Systems—D. C. Livingston. (I.R.E. Convention Record, part 4, pp. 51–56; 1953.) This paper will present a detailed comparison between two different color television systems both of which fall within the broad framework of what might be called the generalized NTSC system. It will be shown that one of these systems is appreciably superior to the other in over-all performance. The paper opens with a brief description of the generalized NTSC system. This is followed by the actual comparison of systems, which is carried out with the aid of a number of "system parameters" whose numerical values reveal the differences in performance between the two systems. These differences will indicate the superiority of one system over the other. Finally, some considerations on percentibility of camera and receiver noise will provide additional evidence of the superiority of the better system.

Phase Measurements at Subcarrier Frequency in Color Television—A. P. Stern. (I.R.E. Convention Record, part 4, pp. 57–60; 1953.) For reliable adjustment and checking of the transmitter and receiver in the NTSC color television system, the possibility of accurate phase measurements at subcarrier frequency is of primary importance. This paper describes the principles and operation of phase measuring equipment recently built in the electronics laboratory of the electronics division of the General Electric Company. Very accurate measurements can be obtained by phase shifting at low frequency and heterodyning to subcarrier frequency. The accuracy is essentially limited by instabilities in the equipment. The over-all error is estimated to be less than 1.0 degree. Some methods employed in using the instrument to measure subcarrier-phase accuracy of a color signal generator are described.

A Monitoring System for NTSC Color Television Signals—C. E. Page. (I.R.E. Convention Record, part 4, pp. 61–65; 1953.) The advent of the NTSC color television signal on a commercial basis will introduce a new problem in signal monitoring. The normal television monitor which displays signal amplitude versus time provides only a fraction of the information required for checking the chrominance portion of the signal. This paper describes an equipment which displays on a cathode-ray oscilloscope the phasor diagram of the chrominance component of NTSC color television signal. This type of display permits rapid visual checking of the chrominance portion of the signal and is equally suitable for signal monitoring service at the transmitter, studio, or color receiver production line. In addition the visual display greatly facilitates the correct alignment of NTSC encoding equipments. The equipment consists basically of a pair of quadrature demodulators whose outputs are fed respectively to the horizontal and vertical plates of an oscilloscope. The equipment described in this paper includes refinements which make it largely self-checking and facilitate rapid operation.

Optimum Utilization of the Radio Frequency Channel for Color Television—R. D. Kell and A. C. Schroeder. (I.R.E. Convention Record, part 4, pp. 91–95; 1953.) To produce a simultaneous television image in color, communications channels must be available. The first of these may be used to transmit the scene brightness, the second the degree of color saturation, and the third the hue or color. For compatibility the brightness is transmitted as amplitude modulation in the usual way. A subcarrier is introduced to carry the other two pieces of information as amplitude and phase modulations. The optimum loading of these two auxiliary communication channels is the major consideration of this paper.

Methods of Matrixing in an NTSC Color Television Receiver—W. M. Quinn, Jr. (I.R.E. Convention Record, part 4, pp. 167–172; 1953.) In order to obtain the required red, blue, and green signals in an NTSC color television receiver, it is necessary to combine or matrix the brightness signal with the two detected components of the chrominance signal. Several methods have been employed to accomplish this matrixing. One method consists of applying the Y or brightness signal to the three grids of a tri-color kinescope and then applying the three-color difference signals (R-Y, B-Y, G-Y) to the individual cathodes. This particular method utilizes the kinescope itself as an adder. Other methods are resistive matrixing, summing amplifiers, and the feedback summing amplifier. All of these methods will be discussed with the most emphasis being given to the feedback summing ampli-

fier. Consideration will be given to linearity, phase distortion, bandwidth, and general performance.

A Color Television Receiver for the NTSC System—K. E. Farr. (I.R.E. Convention Record, part 4, pp. 193–197; 1953.) The basic elements of color television transmission will be outlined, and the salient features of the NTSC system in its present form will be discussed. A receiver designed for this system will be described. The receiver circuits are divided into four basic groups: (1) the monochrome or brightness signal channel, along with sound, deflection sync, and agc; (2) the color decoder and video circuits; (3) the color sync circuits; (4) the deflection, convergence, and power supply circuits. The performance of this receiver will be discussed, and color photographs of color pictures taken from the picture-tube screen will be shown in the slides, as well as circuit details and photographs of the receiver.

Correspondence

Some Russian Terms and Abbreviations*

In two previous articles I have given some notes on Russian circuits and electrical and radio units which were intended primarily for engineers engaged in foreign equipment evaluation. This article continues with some fundamental electrical and radio quantities and their symbols plus a number of terms and abbreviations in common use; many of these are of course found in technical dictionaries, others are not.

Although the Russian words for the fundamental electrical and radio quantities are in general derived from purely Slavic roots, many common English letter symbols are retained in Russian technical literature and circuit diagrams; other letter symbols are taken from the German, e.g., S (Steilheit) is used for transconductance rather than g_m. The German Steilheit and the Russian крутизна both mean literally steepness, i.e., the slope of the grid voltage-plate current curve. Of the words in the list which follows it should be mentioned that сопротивление is sometimes used alone to mean impedance and that проводимость is likewise often used alone to mean admittance. The adjective полное (полная) means simply full or total. The literal meaning of the adjective безваттное (безваттная) is wattless, which explains the significance of the terms in which it appears. The words индукция (induktsiya) and индуктивное (induktivnoye) will be identified readily, only the endings being purely Russian.

напряжение	V	voltage
ток	I	current
сопротивление	R	resistance
индукция	L	inductance
самоиндукция	L	self-inductance
взаимоиндукция	M	mutual inductance
емкость	C	capacitance
реактивное сопротивление	X	reactance
безваттное сопротивление	X	reactance
индуктивное сопротивление	X_L	inductive reactance
емкостное сопротивление	X_C	capacitive reactance
полное сопротивление	Z	impedance
проводимость	G	conductance
безваттная проводимость	B	susceptance
полная проводимость	Y	admittance
крутизна	S	transconductance

The terms of the next list make use of Russian letters for their abbreviations. The abbreviations are perhaps of more practical value than the terms themselves for they are widely used although seldom given in dictionaries.

высокая частота	вч	high frequency
низкая частота	нч	low frequency
промежуточная частота	пч	intermediate frequency
короткие волны	кв	short waves
длинные волны	дв	long waves
дециметровые волны	дмв	decimeter waves
сантиметровые волны	смв	centimeter waves
ультракороткие волны	укв	ultrashort waves
амплитудная модуляция	ам	amplitude modulation
частотная модуляция	чм	frequency modulation
злектродвижущая сила	здс	electromotive force
автоматическое регулирование громкости	арг	automatic volume control
козфициент полеэного действия	кпд	efficiency

The terms in the following list have been gathered largely from Russian circuit diagrams and schematics. Many of these terms have standard abbreviations and these are given; others are abbreviated variously but there seems to be no standard abbreviation and for that reason none is given. Terms taken from the English have been transliterated.

схема (skhema)	—	schematic
контур (kontur)	—	circuit
цоколь (tsokol)	—	socket (socle)
конденсатор (kondensator)	—	condenser
индикатор (indikator)	—	indicator
сигнал (signal)	—	signal; alarm
кварц (kvarts)	—	quartz
стоп (stop)	—	stop
антенна (antenna)	ант	antenna
аккумулятор (akkumulator)	—	storage battery
телефон (telefon)	тфн, тлф	telephone
микротелефон (mikrotelefon)	мтфн	microtelephone
микрофон (mikrofon)	мфн	microphone
ларинг (laring)	—	larynx (microphone)
регулятор (regulyator)	—	regulator
регулирование (regulirovaniye)	—	regulation; control
контролировка (kontrolirovka)	—	control
кабель (kabel)	—	cable
вибратор (vibrator)	виб	vibrator
лампа (lampa)	л	lamp; tube
трансформатор (transformator)	тр	transformer
умформер (German: Umformer)	умф	dynamotor
щиток	—	panel
сеть	—	network
сетка	—	grid
сеточное смещение	—	grid bias
настройка	—	tuning
катушка	—	coil
намотка	—	winding
проводник	—	conductor
проволока	—	wire
громкость	—	loudness (volume)
включитель	вк	switch (on)
выключитель	—	switch (off)
переключитель	—	switch (on-off, DP, or selective)
предохранитель	—	fuse
передатчик	пер	transmitter
приемник	—	receiver
прием	—	reception
усилитель	—	amplifier
питающая часть	—	supply section
рисунок	рис	figure
земля	з	ground
заземление	з	ground connection
зажим	—	terminal
шунт (shunt)	—	shunt
поток	—	flux
лошадиная сила	—	horsepower

In the above listings no effort has been made toward completeness; these basic vocabularies may be expanded indefinitely. Attention is invited to the fact that Russian capital letters and italics vary somewhat from the lower case letters used here.

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Electrical Units in Russian*

Engineers who are engaged in analyzing Russian circuits and equipment are sometimes surprised to learn that Russian employs a system of electrical units very similar to our own, i.e., the units are derived from the names of early European scientists. For example, *ampere*, *volt* and *watt* are in Russian ампер, вольт and ватт, respectively. Russian follows the German in using *hertz* to mean cycle, although цикл is not unknown. Since there is no *h* in the Russian alphabet it becomes a г (*g*) in transliteration; *hertz* then becomes герц (g-e-r-tz). The same applies to *henry* which becomes генри (g-e-n-r-i). Some common units and their abbreviations follow:

ампер	а	ampere
ватт	вт	watt
вольт	в	volt
белл	б	bel
гаусс	гс	gauss
генри	гн	henry
герц	гц	cycle (hertz)
дина	дн	dyne
джоуль	дж	joule
калория	кал	calorie
кулон	к	coulomb
минута	мин	minute
мо	мо	mho
ом	ом	ohm
секунда	сек	second
фарада	ф	farad
час	ч	hour
эрстед	э	oersted

As in English, Russian employs metric-system prefixes that are used as multipliers for their associated base units. Since these multipliers are taken from the Greek and Latin they are not unfamiliar. One exception is that пико (pico), following general European practice, is used in place of micromicro to mean 10^{-12}. Some common multipliers and their abbreviations follow:

пико	п	10^{-12}	micromicro
миллимикро	ммк	10^{-9}	millimicro
микро	мк	10^{-6}	micro
милли	м	10^{-3}	milli
санти	с	10^{-2}	centi
деци	д	10^{-1}	deci
кило	к	10^{3}	kilo
мега	мг	10^{6}	mega
киломега	кмг	10^{9}	kilomega
мегамега	мгмг	10^{12}	megamega

Some examples of multiplied units and their Russian abbreviations are given in the following list:

децибелл	дб	decibel
киловатт	квт	kilowatt
киловольт	кв	kilovolt
килогерц	кгц	kilocycle
миллиампер	ма	milliampere
милливатт	мвт	milliwatt
милливольт	мв	millivolt
миллигенри	мгн	millihenry
мегагерц	мггц	megacycle
мегом	мгом	megohm
микроампер	мка	microampere
микроватт	мквт	microwatt
микровольт	мкв	microvolt
микрофарада	мкф	microfarad

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Synthesis of One Terminal-Pair Passive Networks Without Ideal Transformers*

In the synthesis of one terminal-pair passive networks following Otto Brune's method,[1] one is often confronted with the problem of mutual couplings. In 1949 R. Bott and J. Duffin[2] suggested a method of synthesis that avoids such mutual couplings. Their method is based on a theorem by P. I. Richards[3] which is an application of Schwarz's lemma to the Brune function.

During some research undertaken on the subject at the Research Laboratory of Electronics, Massachusetts Institute of Technology, this writer found the same solution as presented by Bott and Duffin, first by physical reasoning,[4] then by direct continuation of Brune's synthesis procedure. The experience thus earned throws further light on the structure of Bott and Duffin's network, and may be of some interest to IRE readers. The two methods are thus unified in the following procedure, which will be discussed in greater detail in a forthcoming issue of the Transactions of the I.R.E. Professional Group on Circuit Theory.

1. Always start with the Brune synthesis. If confronted with a cycle with an ideal transformer, complete that cycle. (Fig. 1.)

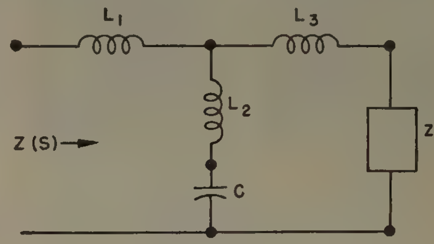

Fig. 1

2. Convert the Brune cycle with ideal transformer into a cycle without ideal transformer as shown in Fig. 2.

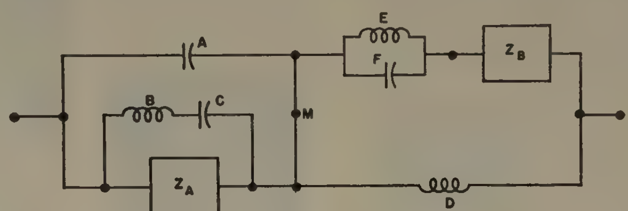

Fig. 2

$$A = \frac{1}{L_1 k^2} \qquad D = L_1$$

$$B = \frac{k^2 L_2^2 c}{k^2 L_2 c + 1} \qquad E = \frac{L_1^2(k^2 L_2 c + 1)}{L_2}$$

$$C = \frac{k^2 L_2 c + 1}{k^2 L_2} \qquad F = \frac{L_2^2 c}{L_1^2(k^2 L_2 c + 1)}$$

$$\frac{1}{Z_3} = \frac{L_1 k^2 - sZ}{k(Z - L_1 s)}$$

$$= \frac{L_1(k^2 - s^2)[csz + c(L_2 + L_3)s^2 + 1]}{k(L_3 s + z)(cL_2 s^2 + 1)} - \frac{s}{k}$$

$$\frac{1}{Z_A} = \frac{1}{kL_1 Z_3} - \frac{(k^2 L_2 c + 1)s}{k^2 L_2(cL_2 s^2 + 1)}$$

$$Z_B = \frac{L_1 k}{Z_3} - \frac{L_1^2(k^2 L_2 c + 1)s}{L_2(cL_2 s^2 + 1)}.$$

The values of the elements of the latter cycle are computed in function of the elements of the Brune Cycle, and no additional computation is required.

3. Proceed with Brune synthesis of Z_A and Z_B.

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I. C. Abrahams

Since 1940, Mr. Abrahams has been employed by the General Electric Company, engaged in development of various phases of radar and television. At present, he is Supervisor of Engineering for the Television Unit of the Electronics Laboratory, where he is concerned with development work on color television.

Mr. Abrahams was associated with Panel 12 of the NTSC. He is a member of Phi Beta Kappa, and the Research Society of America.

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J. Avins (A'39–SM'49) was born in New York, N. Y., on March 18, 1911. He received the A.B. degree from Columbia College in 1932, and the M.E.E. degree from the Polytechnic Institute of Brooklyn in 1949.

J. Avins

Prior to 1941 he was engaged in the design of radio test equipment. From 1941 to 1946 he served in the Signal Corps, initially as a radar instructor, and from 1944 to 1946 as Chief of the Radar Division of the Fort Monmouth Signal Corps Publications Agency. In 1946 he joined the RCA Industry Service Laboratory, RCA Laboratories Division, where he has been engaged in radio and television receiver design.

Mr. Avins is a member of Phi Beta Kappa. He has been active on the I.R.E. Receivers Committee, and is currently Chairman of that committee.

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W. F. Bailey (S'33–A'36–VA'39–SM'51) was born on May 4, 1911, in Buffalo, N. Y. He received the M.E. degree in 1933 and the M.S. degree in 1941 from Stevens Institute of Technology. He has been employed by the Hazeltine Corporation since 1936, where he has done research and development work on television receivers and IFF equipment. Since 1949 he has been working on problems of color television.

W. F. Bailey

Mr. Bailey is an associate member of the AIEE. He was a member of Panel 12 on Color System Analysis of the NTSC, and chairman of Committee 5 on Color Receiver Acceptance Characteristics of Panel 16. He is also vice-chairman of the Long Island Section of the I.R.E.

❖

W. R. G. Baker (A'19–F'28) is vice-president of the General Electric Company, Electronics Park, Syracuse, N. Y. and a leader in the development of radio and television. A graduate of Union College with three degrees, Dr. Baker joined General Electric's Research Laboratory in 1917.

W. R. G. Baker

His first work on radio included the development and testing of radio apparatus for aircraft, submarines, captive balloons, torpedo boats, destroyers, and battleships. Dr. Baker was later made designing engineer.

In 1942 this responsibility was enlarged to include the design of all radio products, and in 1926, he was given complete charge of development, design, and production. He supervised the design of pioneer broadcasting stations WGY in Schenectady, KOA in Denver, and KGO in Oakland, and the Schenectady radio developmental laboratory. The latter aided in maintaining communications with both Byrd Antarctic expeditions.

On the formation of the RCA-Victor Corporation in 1929, Dr. Baker went to Camden, N. J., to head the radio-engineering activities of the new organization. He was in charge of production and later vice-president of engineering and manufacturing.

In 1935 General Electric resumed its radio-receiver activities at Bridgeport, Conn., and Dr. Baker renewed his connections with the company. He was named managing engineer in 1936, a post he held until May, 1939, when he was promoted to the position of manager of the company's radio and television department.

In October, 1941, Dr. Baker was elected a vice-president. His departments was subsequently redesignated the Electronics Department, now one of the nine GE operating departments and producer of radio, radar, television, and similar equipment in the rapidly expanding electronics industry.

The present Electronics Park of the General Electric Company of Syracuse, N. Y. is one of the largest centers of activity in this field. It is the realization for an ambition which Dr. Baker has long carried in his mind. For this the nation is indebted to him.

Under Dr. Baker's direction as chairman of the National Television System Committee, the standards for monochrome telecasting were developed, recommended, and adopted by the FCC. As Director of Engineering for the Radio-Television Manufacturers Association he is actively engaged in co-ordinating the work of the industry on color television. He is also chairman of the present NTSC, which developed the proposed color television standards.

Under his supervision as chairman of the Radio Technical Planning Board, recommendations for frequency allocations of all broadcasting services were formulated.

Dr. Baker was president of the I.R.E. in 1947, a director in 1940 and 1946–1953, and treasurer in 1951–1953. He was Standards Co-ordinator during 1948–1950.

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J. A. Bauer (A'41–SM'53) attended Drexel Institute Evening School in Philadelphia, Pa., while employed in the Long Lines Department of the A. T. & T. Company. He graduated in electrical engineering in 1933 while associated with the Philco Corporation. Here, as factory engineer in 1939, he set up manufacturing test facilities for television receivers on a pilot production basis. Since 1940, he has been with the RCA Victor Division, Camden, N. J., as design engineer, group leader and manager of the Test and Measurements Group. Mr. Bauer served part-time on the faculty of Temple University Technical School, Philadelphia, Pa.

J. A. Bauer

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W. L. Behrend (M'48–SM'53) was born on January 11, 1923, at Wisconsin Rapids, Wis. He received the B.S. degree in 1946, and the M.S. degree in 1947, both from the University of Wisconsin.

Contributors

From 1944 to 1946 he served as an electronic technician in the Navy. In 1947 he joined the RCA Laboratories Division, Princeton, N. J., where he is now with the Systems Research Laboratory, working on antennas, experimental uhf television transmitters, and color television.

W. L. Behrend

Mr. Behrend, in addition to being a member of I.R.E., is a member of Sigma Xi.

❖

F. J. Bingley (A'34–M'36–SM'43–F'50) was born in Bedford, England, on November 13, 1906. He graduated from the University of London. In 1926 and 1927 he received the B.S. degrees in mathematics and physics, respectively.

F. J. Bingley

Mr. Bingley's first employment, in October, 1927, was with the Baird Television Company of London, subsequently to be in charge of their New York laboratories for two years, before joining the Philco Corporation in 1931.

At Philco, he has been associated with the development of transmitting and receiving equipment, as well as with television-systems engineering. He is presently engaged in extensive color television research.

Mr. Bingley is a member of the Franklin Institute.

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W. L. Brewer was born in Mesa, Ariz., on September 30, 1913. He received the B.S. degree from Arizona State College in 1933, the M.S. from the University of Arizona in 1934, and Ph.D. degree from Columbia University in 1942.

W. L. Brewer

From 1939 until the summer of 1942 he taught at the Western Washington College of Education in Bellingham, Wash. He then spent about a year at the Radiation Laboratory of the University of California as a research physicist. This was followed by three years at Oak Ridge, Tenn., as superintendent of technical training and as an assistant superintendent of production. Since March, 1946 he has been with the Eastman Kodak Company in Rochester, N. Y. His current position is supervisor of the physical standards and services section of the Color Technology Division.

Dr. Brewer is a member of the Optical Society of America, and of the Society of Motion Picture and Television Engineers.

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G. H. Brown (A'30–F'41) was born on October 14, 1908, at North Milwaukee, Wis. He received the B.S. degree from the University of Wisconsin in 1930, the M.S. degree in 1931, the Ph.D. degree in 1933, and the professional degree of E.E. in 1942. From 1930 until 1933 he was a Research Fellow in the electrical engineering department at the University of Wisconsin, and from 1933 to 1942 he was in the Research Division of the RCA Manufacturing Company at Camden, N. J. Since 1942, he has been at the RCA, Laboratories at Princeton, N. J., where he is at present Director of Systems Research Laboratory.

G. H. Brown

Dr. Brown is a member of Sigma Xi, the New York Academy of Sciences, and is a fellow of the AIEE.

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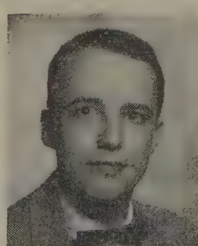
R. P. Burr (A'48–SM'53) was born at Mineola, N. Y., on September 28, 1922. He received the degree of B.E.E. from Cornell University in 1944, after attending Princeton University from 1940 to 1943. He was a technical radar officer in the United States Naval Reserve from 1945 to 1946. In October, 1946, he joined the Hazeltine Electronics Corporation where, in 1947, he became associated with the Research Division, specializing in the design of television signal generating and receiving equipment. From early 1949 to the present, he has worked on color television systems and related apparatus problems.



R. P. Burr

Mr. Burr is a member of the Society of Motion Picture and Television Engineers, and of Eta Kappa Nu.

C. W. Cain was born on November 29, 1908, at Milburn, N. J.

Mr. Cain joined CBS-Hytron in 1952. As development engineer he is associated with the development of laboratory instrumentation in the color laboratory. He was previously with the Burroughs Adding Machine Company and the Radio Corporation of America. At RCA he was in the television "pick-up" tube division which made camera tubes for the guided missile program, and with the RCA advanced development group.

C. W. Cain

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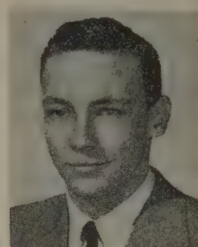
J. B. Chatten (S'50–A'51) was born in New York, N. Y., on November 18, 1927. He received the B.S. degree in electrical engineering from the Massachusetts Institute of Technology in 1950.

Since 1950 Mr. Chatten has been a research engineer with the Philco Corporation, where he has worked on color television and also on color measuring apparatus.



J. B. Chatten

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R. DeCola (A'37–SM'43) was born at Niles, Ohio, on September 7, 1907.

Mr. DeCola started as a commercial radio operator in 1925. From 1929 to 1936 he was radio engineer for Victoreen Radio Company, Workrite Radio Corporation, and General Electric Company. In 1936 he joined Belmont Radio Corporation in charge of the military engineering division and of advanced development, and design of television and FM receivers. In 1942 he became project engineer for the Admiral Corporation in FM radar development; in 1945, as vice president and chief engineer of the Telequip Radio Company, he was engaged in engineering of television sync generators, picture generators, and TV receivers; in 1948 he was chief engineer for the Hazeltine Research Corporation. Since 1950 he has been Director of Engineering for the Admiral Corporation.

R. DeCola

Contributors

R. Dorr (A'52) was born in Chicago, Ill., on March 24, 1921. He received the B.A. degree from Pomona College in 1942. During World War II he had further training in radar at the Massachusetts Institute of Technology in 1942, and in FM radio at Northeastern University in 1943. He conducted graduate studies in physics at the University of California during 1948–1949.

R. Dorr

From 1942–1945, Mr. Dorr was a staff member of the M.I.T. Radiation Laboratory, engaged in operational research in Loran. He was with the Watson Laboratories (Air Force) in 1946 as engineer in charge of the experimental low-frequency Loran Station near North Battleford, Sask. From 1946–1952, he was with the University of California Radiation Laboratory, engaged in electronic instrumentation for nuclear research. He has been with Chromatic Television Laboratories, Inc. since 1952, in the capacity of electronics engineer, with particular emphasis on system analysis and electronic design.

Mr. Dorr is on the faculty of Heald Engineering College, San Francisco, and a member of Phi Beta Kappa.

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E. W. Engstrom (A'25–M'38–F'40) was born in Minneapolis, Minn., August 25, 1901. He received the B.S. degree from the University of Minnesota in 1923.

E. W. Engstorm

After graduation he became associated with the General Electric Company. When the radio engineering and manufacturing activities were transferred to the Radio Corporation of America in 1930, Dr. Engstrom continued as division engineer in charge of photophone or sound motion picture apparatus development and design at Camden, N. J., and assumed engineering responsibilities for RCA's broadcast receivers and radio-tube research.

In 1942, when research activities of RCA were concentrated at Princeton, N. J., he became director of general research, and in 1943 director of research of RCA Laboratories. In 1945 he was elected Vice President in Charge of Research of the RCA Laboratories Division, and in 1951 Vice President in charge of the Division.

In 1949 Dr. Engstrom received the honorary degree of D.Sc. from New York University. In 1949 he received a silver plaquette from the Royal Swedish Academy of Engineering Research, and in 1950 was awarded the Outstanding Achievement Award gold medal from the University of Minnesota for "pioneering in television research."

He is a member of Sigma Xi, and a fellow of the AIEE.

❖

W. R. Feingold (A'53) was born in New York, N. Y., on October 18, 1916. He received the B.S. degree in electrical engineering in 1937 from the Cooper Union Institute of Technology, and the M.S. degree in electrical engineering in 1948 from the Polytechnic Institute of Brooklyn. He is a registered professional engineer of New York State.

W. R. Feingold

From 1937 to 1944 his efforts were confined to the electric power field. Starting with the Roller Smith Co., where he designed high power switchgear, he moved on to the power division of the New York City Board of Transportation. Here he was a member of the design team which handled all new substation work on the Independent Subway System. In 1941 he became a supervisor with The Lummus Co., handling the power, lighting and instrumentation requirements of high octane gasoline refinery plants, synthetic rubber, and munitions chemical plants.

In 1944 he worked with the Hazeltine Electronic Corp., on their IFF Mark V development program. From 1945 to 1948 he was with Munston Manufacturing, as chief engineer in charge of electronic development. Since 1948 he has been a senior television engineer with Emerson Radio and Phonograph Corp., where he was responsible for the design of a number of their large screen television receivers. His present responsibility is the supervision of the company's color television receiver development program.

Mr. Feingold has been an active member of Panels 13 and 16 of the NTSC for the past two years.

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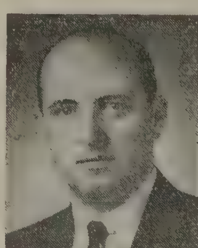
D. G. Fink (A'35–SM'45–F'47) was born on November 8, 1911, at Englewood, N. J. He received the B.Sc. degree in electrical engineering from the Massachusetts Institute of Technology in 1933, and the M.Sc. degree in electrical engineering from Columbia University in 1942.



D. G. Fink

During 1933–1934, Mr. Fink was a research assistant in the M.I.T. departments of electrical engineering and geology. From 1934 to 1952 he was on the editorial staff of *Electronics*, becoming Editor-in-Chief in November, 1946. Since 1952 he has been associated with the Philco Corporation as Director of Research for radio, television and appliances.

Mr. Fink designed the standard loran transmitter in 1941–1943, when on leave to the Radiation Laboratory at M.I.T. In 1946, he was a civilian consultant of the Commander, Joint Task Force One, in charge of preparing damage reports on all electronic material and test facilities for the Bikini atom bomb tests.

He is Chairman, Preparatory Committee on Television, State Department, a member of Tau Beta Pi, Sigma Xi, Eta Kappa Nu, and a fellow of the AIEE.

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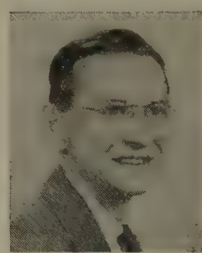
J. F. Fisher (SM'48) was born on February 28, 1911, in Philadelphia, Pa. He attended the Drexel Institute of Technology from 1929 to 1933, graduting in 1936 from the evening school. His co-operative periods while attending Drexel were with the Philco Corporation, with whom he has been employed for eighteen years.



J. F. Fisher

After several years work in quality control, Mr. Fisher joined the Research Division. Projects he has worked on in a supervisory capacity include apparatus for measurement of long persistence cr tubes, propagation studies at vhf and uhf, instrumentation for transient analysis of television receivers and systems, and design of color television terminal equipment. He is now a group engineer on color television systems.

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G. L. Fredendall (A'41–SM'46) was born at Kettle Falls, Wash., on December 20, 1909. He attended the University of Wisconsin, from which he received the Ph.D. degree in 1936. From 1931 to 1936 he taught electrical engineering and mathematics, and engaged in research work in mercury-arc phenomena at the University of Wisconsin.

G. L. Fredendall

Since 1936 Dr. Fredendall has been with the Radio Corporation of America, working on television research. At present he is located at the RCA Laboratories, Princeton, N. J.

Contributors

N. F. Fyler (A'52) was born in Great Falls, Montana, on July 3, 1911. He received the B.S. degree in electrical engineering from Colorado University, and later did graduate work at New York University and Massachusetts Institute of Technology.

N. F. Fyler

Mr. Fyler joined CBS-Hytron in 1951, as supervisor of picture-tube development. Prior to that he was a tube development and television research engineer with RCA Victor and RCA Laboratories, and was chief engineer at Sarkes-Tarzian, Inc.

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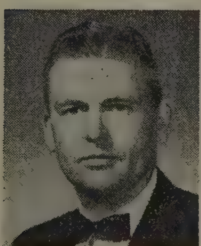
E. E. Gloystein (S'50–A'51) was born in Waco, Neb., on December 6, 1921. He received the B.S. degree from the University of Nebraska, Lincoln, Neb. Since that time he has been employed by the Radio Corporation of America, Victor Division, in Camden, N. J., where he has been engaged in color television development.



E. E. Gloystein

Mr. Gloystein is a member of Sigma Tau as well as the I.R.E.

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J. D. Gow was born at Riverside, Calif., on May 28, 1924. He completed work in electrical engineering in 1942 at San Mateo Junior College, under assignment by the U. S. Army Signal Corps. Since 1943 he has been employed by the Radiation Laboratory of the University of California, where he is currently in charge of the linear-accelerator group. He holds patents on a concentricity meter, high-current ion source, and several secrecy orders in the general fields of electronics and physics. In addition to his work at the Radiation Laboratory, he has been a consultant to Chromatic Television Laboratories, Inc., since 1951.

J. D. Gow

Mr. Gow is a member of the American Physical Society, and an associate member of Sigma Xi.

M. J. Grimes was born in Denver, Pa., on April 16, 1914. He graduated from Wyoming Polytechnic Institute in 1935. From 1935 to 1939 he was employed by Textile Machine Works in Reading, Pa.; from 1941 to 1945, he was with Sensenich Corporation, in charge of mechanical development of aircraft propellers; and from 1945 to 1953, he was in charge of various mechanical aspects of television developments for the Radio Corporation of America, including metal and color kinescopes. At present Mr. Grimes is Vice President and Assistant General Manager of the Reese Padlock Company, Lancaster, Pa.

M. J. Grimes

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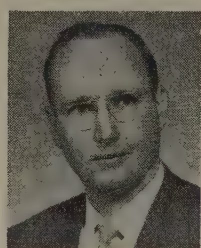
A. C. Grimm (M'48–SM'51) was born in Leonia, N. J., on January 18, 1919. He received the degree of B.E.E. from the Polytechnic Institute of Brooklyn in 1940. Since then he has been associated with the tube department, engineering section, of the RCA Victor Division, Radio Corporation of America. From 1940 to 1950 he was engaged in the design and development of receiving tubes and small power tubes. He has worked on the development of tricolor kinescopes since 1950, and is now product manager for these tubes.



A. C. Grimm

Mr. Grimm is a member of Tau Beta Pi and Eta Kappa Nu, and is a registered professional engineer in electrical engineering.

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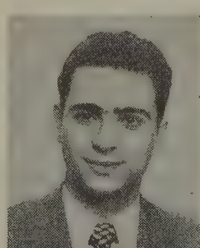
B. Harris (S'48–A'52) was born in New York, N. Y., on October 13, 1927. He received the B.E.E. degree from Cooper Union in 1949, and the M.S. degree in electrical engineering from Columbia University in 1951. During the period 1946–1947, he served in the United States Army.



Bernard Harris

Since 1951, Mr. Harris has been employed as a television development engineer by the New York Industry Service Laboratory, RCA Laboratories Division. He is now pursuing the D.Eng.Sc. degree at Columbia University.

Mr. Harris is a member of Tau Beta Pi.

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C. J. Hirsch (M'39–SM'43–F'51) was born in Pittsburgh, Pa., October 25, 1902. He received his early education in France, returning to this country in 1916. He was awarded the A.B. degree and the E.E. degree from Columbia University in 1923 and 1925, respectively. After graduation he was employed as development engineer by several radio laboratories, including the John Hays Hammond Laboratory in Gloucester, Mass., the Thomas A. Edison Industries in Orange N. J., and the Fada Radio and Electric Company. From 1933 to 1937 he was chief engineer of radio companies in France and Italy, returning to the United States in 1937 to become chief engineer for the Majestic Radio and Television Corporation.

C. J. Hirsch

At the beginning of the war he joined Hazeltine Electronics Corporation, to work on secondary radar and IFF systems. During the second half of the war he was in charge of the surface equipment section of a coordinated secondary radar system development. This development was carried out co-operatively by several radio manufacturers who pooled their engineers to form an integrated development staff under the direction of the Hazeltine Electronics Corporation. He was awarded a Certificate of Commendation by the United States Navy for outstanding work in the radar and IFF fields.

After the war Mr. Hirsch became chief engineer in charge of radio aids to navigation, in which capacity the work on distance-measuring equipment (DME) was carried out. He is now chief engineer of the research division of the Hazeltine Corporation, and has been actively engaged in color television research since 1949.

Mr. Hirsch is a fellow of the Radio Club of America, and has been an active member of various government and industry committees, including the National Television Society Committee, where he was secretary of Panel 13 on Color Video Standards. Mr. Hirsch also was chairman of the Long Island Subsection (now a Section of the I.R.E.) for 1952–53.

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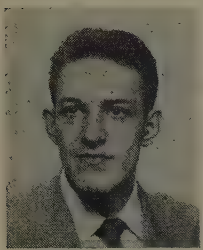
J. S. Horvath (A'49) was born in New York, N. Y., on February 13, 1926. During World War II he served in the U. S. Navy as an electronics technician. Upon discharge, Mr. Horvath was employed until

Contributors

1947 as a radio and television instructor at the New York Technical Institute of New Jersey. After graduation from the RCA Institutes in 1949 he was employed as a test engineer on radar equipment at Lavoie Laboratories Inc. Since 1950 he has been engaged in television and transistor circuit development at the RCA Industry Service Laboratory.



J. S. HORVATH

P. W. Howells was born in Dunkirk, N. Y., on April 24, 1921. He received the B.E.E. degree from Syracuse University in 1942. After graduation he joined the General Electric Company, where he worked until 1947 on electronic systems development. In 1947 he joined the staff of the University of Maine, where he taught and did graduate work, receiving the M.E.E. degree in 1949. Since that time he has been associated with the Electronics Laboratory of the General Electric Company, Syracuse, N. Y., engaged in color television problems.

P. W. HOWELLS

Mr. Howells is a member of Tau Beta Pi, Sigma Xi and RESA, and has participated in the work of NTSC Panels 13 and 19.

W. L. Hughes (S'48–A'50) was born in Rapid City S.D., on December 2, 1926. He received the B.S. degree in electrical engineering from South Dakota State School of Mines and Technology in 1949, and the M.S. and Ph.D. degrees in electrical engineering from Iowa State College in 1950 and 1952, respectively.

W. L. HUGHES

Dr. Hughes worked as a transmitter engineer for the Black Hills Broadcast Co. of Rapid City while a student, and was active in the engineering development of Iowa State's television station WOI-TV. During World War II he worked for two years in aviation electronics for the U. S. Navy. At present he is assistant professor of electrical engineering at Iowa State College.

Dr. Hughes is an associate of Eta Kappa Nu, Sigma Xi, and Pi Mu Epsilon.

J. J. Insalaco was born in New York, N. Y., on May 23, 1923. He served in the U. S. Navy from February, 1943 to December, 1945 as an electronic technician. He received the B.E.E. degree from New York University in 1950 and, at present, is completing work towards the M.E.E. degree at the same college.

J. J. INSALACO

From 1950 to 1952 Mr. Insalaco was employed by the Bell Aircraft Corporation in Buffalo, N. Y., as an electronic systems engineer attached to the missile-carrier group. He joined the circuits and systems sections of Sylvania Electric Products, Inc. in 1952, and is presently a member of the television section of the company's physics laboratories at Bayside, N. Y.

K. Karstad was born in Norway, in 1918. He majored in electrical engineering, graduating from Norway's Technical University, Trondheim, in 1942. While a postgraduate student in 1943, he worked as an instructor in radio engineering at the University. In early 1944 he was employed at the ASEA concern in Vesteraas, Sweden.

K. KARSTAD

For the next two years Mr. Karstad was an officer in the Royal Norwegian Navy, serving Norway and Great Britain in the technical branch dealing with underwater sound. In 1946 to 1952 he was in charge of the Electronics Maintenance Department, Sonar Section, of the Norwegian Navy.

From 1948 to 1950, on leave of absence and as an Honorary Fellow of the American Scandinavian Foundation, Mr. Karstad spent the time with the RCA Laboratories Division, Princeton, N. J. He returned in 1952, where he is now continuing his work in color television research.

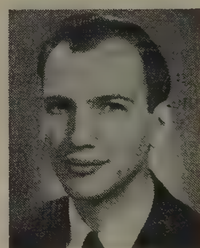
J. H. Ladd (M'53) was born in Kewanee, Ill., on September 6, 1918. He received the B.S. degree in chemistry in 1940, and the M.S. and Ph.D. degrees in physical chemistry in 1942 and 1947, respectively, all from the University of Illinois.

From 1942 to 1946 he served as an officer in the Army Chemical Corps Technical Command, doing developmental work on chemical agents, flame attack against fortified positions, use of radioactive tracers, and launching of guided missiles. Since 1947 he has been with the Color Technology Division of Eastman Kodak Company, as development engineer on color photographic printers, analog computers, and other color photographic equipment problems.

J. H. LADD

Dr. Ladd is a member of the Society of Motion Picture and Television engineers, the American Physical Society, and the American Chemical Society. He is a Major in the Army Chemical Corps Reserve.

D. C. Livingston was born in Chicago, Ill., in 1921. He received the Ph.B. degree in physics at the University of Wisconsin in 1943. From 1944 to 1946 he worked on the atomic bomb project at the Metallurgical Laboratory, Chicago, and at the Los Alamos Laboratory, New Mexico, participating in the Bikini atomic bomb tests as a member of the Los Alamos field group.



D. C. LIVINGSTON

Mr. Livingston pursued graduate studies towards the Ph.D. degree in physics at the Ohio State University from 1946 to 1952, and in January, 1952, joined the staff of the Bayside Research Center of Sylvania Electric Products, Inc., where he is engaged in studies on color television system analysis.

During the last year he has served on Panel 13 Gamma Subcommittee, and Panel 19 Symbols Subcommittee, of the NTSC.

B. D. Loughlin (A'40–M'45–SM'53) was born in New York, N. Y., on May 19, 1917. He received the B.E.E. degree in 1939, and the E.E. degree in 1945, from Cooper Union. In 1946 he received the M.S. degree in electrical engineering from Stevens Institute of Technology.

B. D. LOUGHLIN

Since 1939 he has been employed in research and development on FM and television receivers, IFF equipment, and color television at the Hazeltine Corp.

Mr. Loughlin received the Vladimir K. Zworykin Television Prize for 1952.

Contributors

A. V. Loughren (A'24–M'29–SM'43–F'44) was born in Rensselaer, N. Y., on September 15, 1902. He received the B.A. and the E.E. degrees from Columbia University in 1923 and 1925, respectively.

A. V. Loughren

Joining the Research Laboratory of the General Electric Company upon graduation, Mr. Loughren spent two years concerned with the problems arising out of the adaptation of vacuum tubes to circuits; and the following two and a half years in the radio engineering department. In 1930 he transferred to the RCA Manufacturing Company at Camden, N. J., where he was engaged in designing radio receivers, loudspeakers, and phonograph pickups. In 1934, he rejoined the General Electric Company at Bridgeport, Conn., to work on the design of radio receivers.

In 1936 Mr. Loughren joined the laboratories of the Hazeltine Corp. He is now director of research of the company, and executive vice president of its subsidiary, Hazeltine Research Inc.

Mr. Loughren has been awarded twenty-nine U. S. patents for his many contributions to the advancement of the electronic art. He is a member of Phi Beta Kappa, Sigma Xi, and Tau Beta Pi.

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A. C. Luther, Jr. (S'49–A'50) was born in Philadelphia, Pa., on December 5, 1928. He received the B.S. degree in electrical engineering from the Massachusetts Institute of Technology in 1950. Following graduation he joined the Television Terminal Equipment Engineering Group at RCA Victor, Camden, N. J. Since that time he has worked on broadcast studio equipment including sync generators, monochrome and color cameras, and color-test equipment.

A. C. Luther, Jr.

Mr. Luther is a member of Eta Kappa Nu, and an associate member of Sigma Chi.

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D. L. MacAdam was born on July 1, 1910, in Philadelphia, Pa. He was graduated from Lehigh University in 1932 with the B.S. degree in engineering physics. From 1932 to 1936 he was a teaching fellow at the Massachusetts Institute of Technology, where he received the Ph.D. degree for work on optics, photography, and color measurements. He was a volunteer assistant at the Bartol Research Laboratories during the summer of 1932, specializing in cosmic ray research. In 1936, he became associated with the Eastman Kodak Company, Rochester, N. Y., where he is now research associate.

D. L. MacAdam

Dr. McAdam is a co-author of the M.I.T. "Handbook of Colorimetry," and the recently published book, "The Science of Color."

He is active in the Optical Society of America, the Society of Motion Picture and Television Engineers, the U. S. National Committee of International Commission on Illumination (Technical and Secretariat Committee on Colorimetry), and the American Standards Association Sectional Committee on Optics (Chairman, Subcommittee on Color Measurements).

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K. McIlwain (A'31–M'40–SM'43–F'48) was born on September 4, 1897, in Philadelphia, Pa. He received the B.S. degree in 1918 from Princeton University, and the B.S.E.E. degree in 1921 and the E.E. degree in 1930, both from the University of Pennsylvania.

K. McIlwain

From 1921 to 1924 Mr. McIlwain was with the Bell Telephone Company of the Pennsylvania Engineering Department. For the next sixteen years he was a professor at the Moore School of Electrical Engineering of the University of Pennsylvania. From 1940 to date he has been the Chief Consulting Engineer of the Hazeltine Electronics Corporation.

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C. Masucci (S'44–A'47) was born in Brooklyn, N. Y., on January 29, 1923. He received the B.E.E. degree in 1944 from the College of the City of New York, and, at present, is completing work towards the M.E.E. degree at the Polytechnic Institute of Brooklyn.

He served in the U. S. Navy from 1944 to 1946. From 1947 to 1948, he was employed by the Western Electric Company as a layout and specification engineer. He joined Sylvania Electric Products, Inc., in 1948, where he is presently a member of the television section of the company's physics laboratories, at Bayside, N. Y.

C. Masucci

Mr. Masucci is a member of the AIEE, and the American Physical Society as well as Institute of Radio Engineers.

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W. C. Morrison (S'40–A'41–SM'49) was born on September 13, 1915, at Sioux City, Ia. He received the A.B. degree in 1937 from Morningside College, Sioux City, and the B.S. and M.S. degrees in 1939 and 1940 respectively, from the University of Iowa.

W. C. Morrison

He was employed by the RCA Manufacturing Company, Camden, N. J., from 1940 to 1942. In 1942 he transferred to the RCA Laboratories, Princeton, N. J., where he is employed in the transmitter section of the Systems Research Laboratory.

Mr. Morrison is a member of Sigma Xi, Tau Beta Pi, and Eta Kappa Nu.

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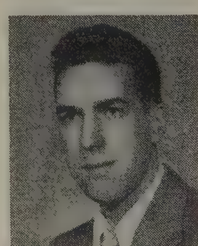
R. G. Neuhauser was born August 19, 1927 in Soudersburg, Pa. He received the B.S. degree in electrical engineering at Drexel Institute of Technology in 1949. He was employed by Radio Corporation of America under a co-operative training program from 1946 to 1949, and joined the company as a full-time engineer in 1949. His first assignments included design of test equipment for kinescopes and color kinescopes. Since 1950 he has devoted himself to application work and designing of test equipment, particularly for all types of camera tubes.



R. G. Neuhauser

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R. C. Palmer (S'42–A'43–M'50) was born October 9, 1922, in Washington, D. C He received the B.E.E. degree from the

Contributors

University of Virginia in 1943, and has done subsequent graduate work in physics at the Stevens Institute of Technology. From 1943 to 1944, he was employed by the General Electric Company, and from 1944 to 1946 by the Tennessee-Eastman Corporation, Oak Ridge, Tenn. Since 1946 he has been located with the Allen B. Du Mont Laboratories, Inc., working chiefly with studio television equipment, color television, and vacuum-tube development. He is presently a project engineer in the Research Division.

R. C. Palmer

Mr. Palmer is an associate of the AIEE, and a member of Tau Beta Pi and Sigma Xi.

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J. E. Pinney was born September 10, 1924, in Columbia, Mo. He attended Iowa State College for one year, served three years in the Air Force Weather Service, and then returned to Iowa State, receiving the B.S. degree in physics in 1947.

J. E. Pinney

Following graduation he joined the Color Technology Division of Eastman Kodak Company, where he is currently employed as a development engineer specializing in color sensitometry.

Mr. Pinney is an associate member of the Optical Society of America, a member of Phi Kappa Phi, and Pi Mu Epsilon.

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J. A. Rado (A'39–M'45–SM'45) was born in Leonia, N. J. on Jan. 26, 1912. He attended Columbia College and Columbia School of Engineering, receiving the A.B. and B.S. degrees. In 1936 he became a member of the Columbia Broadcasting System, participating in the television development program. In 1938, he joined Hazeltine Corporation where, until the war, he was engaged in development of television receivers and test equipment. During the war he contributed to the development of IFF equipment for the armed forces.

J. A. Rado

After the war, Mr. Rado spent several years with Federal Telecommunications Laboratories and the New London Instrument Company, before returning to Hazeltine in 1950. He is now a member of the advanced research group at Hazeltine working on color television, with particular attention to colorimetry and associated problems.

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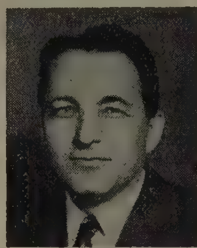
J. R. Rae (M'53) was born in San Francisco, Calif., on December 9, 1907. He was graduated from the Massachusetts Institute of Technology in 1929, with the B.S. and M.S. degrees in electrical engineering.



J. R. Rae

Since 1929, he has been employed in the Long Lines Department of the American Telephone and Telegraph Company, working principally in the field of transmission engineering. In recent years his work has been concerned largely with coaxial cable systems, microwave radio relay systems, and television transmission.

Since January, 1953, Mr. Rae has been General Methods Engineer of the Long Lines Department, responsible for technical methods used in engineering, construction, and maintenance of Long Lines plant.

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J. G. Reddeck, was born in Greensboro, N. C., on June 4, 1922.

Mr. Reddeck received the B.S. degree in electrical engineering from North Carolina State College, Raleigh, in 1947. From 1947 to October, 1953, he was employed by RCA Laboratories, Princeton, New Jersey. He is now with the engineering department of Crosley Avco, Cincinnati, Ohio.

J. G. Reddeck

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D. Richman (S'42–A'45–SM'52) received the degree of B.E.E. from the College of the City of New York in 1943, and the degree of M.E.E. from the evening session of the Polytechnic Institute of Brooklyn in 1948. Since 1943 he has been with Hazeltine Corporation in a number of research activities relating to superregeneration, frequency modulation, direction finding systems, electromagnetic radiation directivity, television receiver design, color television systems, and synchronization for color television.

D. Richman

Mr. Richman is a member of Eta Kappa Nu, and Sigma Xi.

A. A. Rotow (SM'52) was born in Tomsk, Russia. He received the B.S. degree in electrical engineering and physics from the University of Belgrade, Yugoslavia, and the M.S. degree in physics from Franklin and Marshall College, Lancaster, Pa. He was employed by the Ikarus airplane factory in Yugoslavia as Manager of the Physical Laboratories.

A. A. Rotow

During World War II he was a reserve lieutenant in the Yugoslav Royal Air Force and later a civilian engineer with the U. S. Army. In 1948 he came to the United States and has since been employed by the Radio Corporation of America, working on camera tube development.

Mr. Rotow is a member of the AAAS, and Sigma Pi Sigma.

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W. E. Rowe was born in Red Oak Ia., on August 5, 1912.

Mr. Rowe joined CBS-Hytron in 1951. As development engineer in the color development laboratory, he has specialized in photographic procedures and techniques, and fabrication of tricolor screens. His experience covers all branches of photoreproduction in the graphic arts industry. Before his present association, he was with the printing and engraving company of St. Anthony's Guild, Paterson, N. J., and headed Rowe Engravers, the company he formed after his wartime service.

W. E. Rowe

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R. E. Shelby (A'29–M'36–SM'43–F'48) is a native of Texas, and a graduate of the University of Texas, where he received the degrees of B.S. in electrical engineering, B.A. and M.A.

R. E. Shelby

He has been engaged in television engineering work for the National Broadcasting Company since 1929, and has played an active part in the development of television broadcasting in this country. He has held several engineering executive positions at NBC, including Director of Technical Development, and Director of TV Technical Operations for the Television Network. At present

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he is Director of the Color TV Systems Development Project for the Engineering Department.

During World War II, Mr. Shelby directed NBC's wartime research and development activities, including the development of an airborne television reconnaissance system for the U. S. Navy. He also served as Technical Consultant to Division 5 of the National Defense Research Committee. He has participated actively for a number of years in the television standardization work of various industry committees, including the National Television System Committee, the Radio Technical Planning Board, and Radio-Television Manufacturers Association.

Mr. Shelby is chairman of the I.R.E.'s Television Systems Committee, and a member of the Standards Committee. He is a fellow of the AIEE, and a member of SMPTE. He is licensed as a professional engineer by the State of New York, and is a member of Tau Beta Pi, Phi Beta Kappa, Eta Kappa Nu, and Sigma Xi. He is a member of the present NTSC, which has recommended specifications for a compatible color television signal to the FCC, and is chairman of its Panel 17 on Networking and Broadcasting.

D. B. Smith (A'35–SM'44–F'48) was born in Newton, N. J. He attended the Massachusetts Institute of Technology, receiving the B.S. and M.S. degrees. He thereafter joined the Philco Corporation (then known as the Philadelphia Storage Battery Company), in which he held various positions concerned with research and engineering. In 1945, he was appointed Vice President in Charge of Research Activities, and in 1946, elected a Director of the corporation.

D. B. Smith

Mr. Smith was a member of the first National Television System Committee, organized as a consequence of the first FCC television hearing, and was chairman of one of its panels. He was a member of the Radio Technical Planning Board, chairman of its Panel on television, chairman of the RMA Television Systems Committee, and a member of the Joint Technical Advisory Committee. He was active in the formation of the second NTSC, of which he is vice-chairman, and chairman of its Ad Hoc Committee on Television which formulated the major color program, and served as chairman of Panel 18 on Co-ordination of the NTSC.

Mr. Smith is a member of the AIEE, Tau Beta Pi, Eta Kappa Nu, and Sigma Xi.

A. H. Turner (A'30) was born in Norfolk, Va., on April 6, 1903. He received the B.S. degree in electrical engineering from the University of Delaware in 1925. From 1925 to 1927 he was employed in the general engineering laboratory of the General Electric Company to study long- and short-wave radio propagation. From 1927 to date he has been employed by the Victor Talking Machine Company and the Radio Corporation of America. Since 1930 Mr. Turner has been engaged in work on uhf and microwave receivers, television receivers, and terminal equipment.

A. H. Turner

F. S. Veith (M'46–SM'51) received the M.S. degree in electrical engineering in 1937 from the Swiss Federal Institute of Technology. From 1938 to 1941 he held a graduate assistantship at the Pennsylvania State College and received the M.S. degree in physics in 1940.

F. S. Veith

During the war Mr. Veith was first assigned to the Air Corps, teaching simulated instrument flying, and then to the Signal Corps, where, after training with the American Telephone and Telegraph Company, he was in charge of construction and operation of fixed communications' centers. After the war he joined Sylvania Electric Products Company Research Laboratories, working on microwave radiations. In 1946, he came to RCA at Lancaster, Pa., working on magnetrons, and in 1950 joined the pickup and phototube group. At present he is in charge of pickup-tube engineering.

Mr. Veith is a fellow of the AAAS, a member of the American Physical Society, and Sigma Pi Sigma.

J. F. Wilhelm (S'41–A'44–M'47–SM'51) was born on November 21, 1920, in Toledo, Ohio. He received the B.S. degree in electrical engineering from the University of Toledo in 1942.

J. F. Wilhelm

From that time he has been employed by the tube department of the RCA Victor Division, Radio Corporation of America, at the Harrison, N. J. plant, as a cr tube production engineer; in 1943 to 1949, at the Lancaster, Pa. plant, in charge of developing electrical specifications for cr tubes and phototubes. During this period he served on RMA and JETEC committees on cr tube standards. Since 1949, he has been engaged in design and development work on tricolor kinescopes.

For two years Mr. Wilhelm has been in charge of color tube product development engineering at the Lancaster, Pa., plant.

R. Zitta was born in New York, N. Y., on May 28, 1920. He was employed by Western Electric Company from 1941 to 1944 as a radar technician. From 1944 to 1946 he served in the U. S. Navy as an electronic technician. Upon his discharge from the Navy, he returned to Western Electric as a test set technician. In 1948, he joined Sylvania Electric Products, Inc., and is presently a senior technician of the television section of the Company's physics laboratories at Bayside, N. Y.

R. Zitta

I-R-E News and Radio Notes

IRE Officers for 1954 Announced

At its meeting on November 11, 1953, the Board of Directors announced the results of the elections for officers and directors of the Institute as follows:

President, 1954: William R. Hewlett, Hewlett Packard Company, Palo Alto, Calif.

Vice President, 1954: Maurice J. H. Ponte, Compagnie Generale de Telegraphie Sans Fil, Paris, France

Directors-Elected-at-Large, 1954–1956: Axel G. Jensen, Bell Telephone Laboratories, Inc., Murray Hill, N. J.; George Rappaport, Aircraft Radiation Laboratory, Wright-Patterson Air Force Base, Dayton, Ohio

Regional Directors, 1954–1955: Region 1, Lucius E. Packard, Technology Instrument Corporation, Acton, Mass.; Region 3, Harry W. Wells, Carnegie Institute of Washington, Washington, D. C.; Region 5, Charles J. Marshall, Aircraft Radiation Laboratory, Wright-Patterson Air Force Base, Dayton, Ohio; Region 7, Joseph M. Pettit, Stanford University, Stanford, Calif.

Annual Award Recipients Announced

The names of the recipients of I.R.E. awards for 1954 were announced at the November 11th meeting of the I.R.E. Board of Directors.

The 1954 Founders' Award, given only on special occasions in recognition of leadership in the planning and administration of important technical developments, was bestowed this year on Dr. Alfred N. Goldsmith, Editor of the PROCEEDINGS OF THE I.R.E.

The Vladimir K. Zworykin Television Prize Award for 1954 was given to Mr. Alda V. Bedford, RCA Laboratories Division, for his contributions to the principle of mixed highs and its application to color television. The award is presented to engineers who have made the most important contributions to electronic television.

The Morris Liebmann Memorial Prize, one of the highest awards in the radio engineering field, was bestowed on Dr. Robert Warnecke, Technical Director of the Compagnie Generale de Telegraphie Sans Fil, Paris, France, for his valuable contributions and scientific advancements in the field of electron tubes and the magnetron class of traveling-wave tubes.

Dr. Harold A. Zahl, Director of Research of the Signal Corps Engineering Laboratories, Fort Monmouth, N. J., was named the recipient of the Harry Diamond Memorial Award for 1954, for his technical contributions, his long service, and his leadership in the U. S. Army Signal Corps research program. This award is given to persons in government service for outstanding work in the field of electronic research.

The Board of Directors also elected seventy-six members of the I.R.E. to the Fellow Grade, effective January 1, 1954.

The awards will be presented at the Institute's annual banquet at the Waldorf-Astoria Hotel, New York City, on March 24, 1954, during the National Convention.

Copies of the first Color Television issue of the PROCEEDINGS, published in October, 1951, are still available at the following prices: $1.00 for I.R.E. members; $2.25 for non-members. The 1951 issue, combined with this present one, will form a complete bibliography and record of the development of color television that is of major historical significance to all electronics engineers.

Tape Recording of Color TV Pictures Shown by RCA

The recording of television pictures on magnetic tape in color and in black-and-white was publicly demonstrated for the first time on December 1, 1953 by RCA at its laboratories at Princeton, N. J. Although the video tape equipment is still in the developmental stage, it was estimated that it would be ready for commercial use in about two years.

The demonstration featured a simultaneous side-by-side comparison of a live color television program fed directly to one receiver and at the same time recorded on tape and played back instantly to a second receiver. The program originated in NBC studios in New York City and was beamed by microwave radio across the 45-mile path to Princeton where it was received and recorded.

The equipment used in the demonstration utilized a single magnetic tape, ½-inch wide, on which five parallel channels were recorded, one for each of the three primary signals, one for the synchronizing signal, and one for the sound signal. The four-minute program was recorded at a tape speed of 30 feet per second on a 17-inch reel. Work is now under way towards developing a reel 19 inches in diameter which will carry a 15-minute program.

Magnetic tape recording of television pictures offers several advantages over the present method of recording on film. Since a recorded tape requires no further processing, it may be played back immediately and eliminates the time and expense associated with developing and processing film. Moreover, an unlimited number of magnetic tape recordings can be made quickly. In addition, recorded tapes can be demagnetized and re-used many times over.

Since the tape can be re-used, it is estimated that recording a color television program on tape would cost only one-twentieth as much as a film recording, and one fifth as much as film recording in the case of a black-and-white program.

Calendar of COMING EVENTS

IAS Twenty-Second Annual Meeting, Hotel Astor, New York, N. Y., January 25–29

IRE-AIEE Scintillation Counter Symposium, Shoreham Hotel, Washington, D. C., January 26–27

IRE-IAS-ION-RTCA Conference on Electronics in Aviation, Astor Hotel, New York City, January 27

1954 Sixth Southwestern IRE Conference and Electronics Show, Tulsa, Okla., February 4–6

IRE-AIEE-ACM Computer Conference, Ambassador Hotel, Los Angeles, Calif., February 11–12

Society of Women Engineers, National Convention, Mayflower Hotel, Washington, D. C., March 5–7

1954 IRE National Convention, Waldorf Astoria Hotel and Kingsbridge Armory, New York, N. Y., March 22–25

IRE 8th Annual Spring Technical Conference, Engineering Society of Cincinnati Building, Cincinnati, Ohio, April 24

Society of Motion Piction & TV Engineers, 75th Annual Convention, Hotel Statler, Washington, D. C., May 3–7

IRE-AIEE-RETMA Electronic Components Symposium, U. S. Dept. of Interior Auditorium, Washington, D. C., May 4–6

IRE New England Radio Engineering Meeting, Sheraton Plaza Hotel, Boston, Mass., May 7–8

IRE-AIEE-IAS-ISA National Telemetering Conference, Morrison Hotel, Chicago, Ill., May 24–26

IRE-RETMA Radio Fall Meeting, Hotel Syracuse, Syracuse, N. Y., October 18–20

British Institution of Radio Engineers 1954 Convention, Oxford University, Oxford, England, July 8–12

I-R-E News and Radio Notes

I-R-E Members Elected Officers of the SMPTE

Two members of the I.R.E. have been elected officers of the Society of Motion Picture and Television Engineers. Their election was announced at the opening luncheon of the society's recent 74th semiannual convention at the Statler Hotel, New York City. Pictured here, with George W. Colburn, *right*, the society's new treasurer, are Barton Kreuzer, *left* (A'29–VA'39–M'48) financial vice president, and Axel G. Jensen, *center*, (A'23–M'26–F'42) engineering vice president. Mr. Jensen was recently elected a Director of the I.R.E. for a term of three years beginning January 1, 1954.

NEREM Sets 1954 Meeting

The New England Radio Engineering meeting, sponsored by the North Atlantic Region of the I.R.E., will be held May 7 and 8, 1954, at the Sheraton Plaza Hotel, Boston, Mass. Registration at 1:00 P.M. will open the meeting on Friday, May 7. The Technical sessions, for which an excellent group of speakers is being selected, will be held from 2:00 P.M. to 5:00 P.M. on Friday and 9:00 A.M. to 4:00 P.M. on Saturday. The exhibits will be open from 1:00 P.M. to 9:00 P.M. Friday, and from 8:30 A.M. to 5:00 P.M. Saturday.

The General Chairman of the meeting is Ivan G. Easton, Cambridge, Mass.; Exhibit Chairman is Robert A. Water, Waltham, Mass.; and the program is under the chairmanship of H. Gunther Rudenberg, Melrose, Mass.

Digital Storage Devices Symposium

The Philadelphia Sections of the I.R.E. and the A.I.E.E. will sponsor a Symposium of Digital Storage Devices under the supervision of the local chapters of the IRE Professional Group on Electronic Computers and the A.I.E.E. Computer Discussion Group. The Symposium is to be held at the Harrison Laboratories, University of Pennsylvania, on six consecutive Tuesday evenings, starting February 9, 1954.

The topics and speakers are as follows: February 9, "Ferroelectric Storage Devices," J. R. Anderson, Bell Labs.; February 16, "Magnetic Drums and Tapes," S. N. Alexander and J. Rabinow, National Bureau of Standards; February 23, "Ferromagnetic Storage Devices," T. H. Bonn, Eckert-Mauchly Div., Remington-Rand; March 2, "Electrostatic Storage Devices," J. Pomerene, Institute for Advanced Study, Princeton; March 9, "Acoustic Storage Devices," J. Koch, Technitrol; and March 16, "Summary and Evaluation," A. Samuel, I.B.M., Inc.

Admission for the series is $3.00 for professional society members, $4.00 for nonmembers, and $1.00 for individual sessions. Persons desiring additional information should contact Stanley B. Disson at the Burroughs Corp., 511 N. Broad Street, Philadelphia, Pa.

Conference on Transistor Circuits

A two-day National Conference on Transistor Circuits will be held in Philadelphia on Thursday and Friday, February 18 and 19, under the sponsorship of the IRE Professional Group on Circuit Theory, and the Science and Electronics Division of the A.I.E.E. Emphasis in the technical sessions will be on material not previously available in the literature, and the program is designed to be of greatest value to engineers who already possess some knowledge of transistor circuit behavior.

The University of Pennsylvania, host for the Conference, has made the University Museum Auditorium available for all technical sessions. Lunch will be served at the Museum on both days, and an informal cocktail-buffet will be held on Thursday evening at the Penn-Sherwood Hotel.

Advance registration forms have been mailed to all members of the sponsoring groups. Anyone interested in attending who has not received these forms by January 15th should contact L. H. Good, RCA Victor Building 10-5, Camden, N. J. Since the facilities available for the Conference are limited, final plans will be based on the number of advanced registrants.

The tentative technical program for the Conference is as follows:

Thursday morning, February 18: Properties and Representation of Transistors; Chairman, J. J. Suran, General Electric Co. (1) "An Engineering View of Transistor Physics," J. M. Early, Bell Telephone Labs.; (2) "A New Equivalent Circuit for Junction Transistors," J. Zawels, RCA Victor Division; (3) "Circuit Implications of Surface-Barrier Transistors," J. B. Angell, Philco Corp.; (4) "Variation of Junction Transistor Parameters with Operating Point and Temperature," J. S. Schaffner, General Electric Co.

Thursday afternoon, February 18: Junction Transistors in Linear Circuits; Chairman, J. G. Linvill, Bell Telephone Labs. (5) "Transistor Circuits Utilizing Complementary Symmetry," G. C. Sziklai, RCA Labs.; (6) "Compensation Techniques in Transistor Circuit Design," E. R. Kretzmer, Bell Telephone Labs.; (7) "Neutralization of Transistor Band-Pass Amplifiers," F. P. Keiper, Philco Corp.; (8) "Contrasts in Feedback Theory for Transistors and Vacuum Tubes," S. J. Mason, Massachusetts Institute of Technology; (9) "Noise in Transistor Circuits," P. L. Bargellini, University of Pennsylvania and RCA Victor Division.

Friday morning, February 19: Junction Transistor Amplifiers; Chairman, T. R. Finch, Bell Telephone Labs. (10) "Summing and Integrating Amplifiers," F. H. Blecher, Bell Telephone Labs.; (11) "Transistor Power Amplifiers," R. G. Shea, General Electric Co.; (12) "Tetrode I-F Amplifiers," L. O. Schimpf, Bell Telephone Labs.; (13) "Transistor D-C Amplifiers," C. R. Hurtig, Lincoln Laboratory, M.I.T.; (14) "A Carrier-Frequency Feedback Amplifier," R. E. Yaeger, Bell Telephone Labs.

Friday afternoon, February 19: Nonlinear Applications of Junction Transistors; Chairman, A. W. Lo, RCA Labs. (15) "Large-Signal Low-Frequency Behavior of Junction Transistors," J. J. Ebers, Bell Telephone Labs.; (16) "Transient Behavior of Junction Transistors," J. L. Moll, Bell Telephone Labs.; (17) "Junction Transistor Switching Characteristics," D. E. Deuitch, RCA Victor Division; (18) "Junction Transistor Switching Circuits," J. T. Warnock, Philco Corp.

I-R-E News and Radio Notes

1953 Electronics Symposium Proceedings Published

The executive committee of the 1953 Electronic Components Symposium has announced the publication of the proceedings of the symposium held April 29–May 1, 1953 at Pasadena, Calif.

The complete text of some thirty papers by recognized authorities in the electronics field appears in the proceedings, which are on sale at the Los Angeles Division of Stanford Research Institute, 621 South Hope St., Los Angeles, at $4.50 per copy.

The general sessions under which papers were presented and have been published are: "General Component Problems," "Environment and Packaging," "Tubes and Tube Reliability," "Component Reliability," "Resistors, Capacitors and Dielectrics," and "Devices and Materials." The major addresses presented during the luncheon and dinner meetings are also included.

Sponsors of the symposium were the Radio Electronics Television Manufacturers Association, the American Institute of Electrical Engineers, the Institute of Radio Engineers, and the West Coast Electronic Manufacturers Association.

Scintillation Counter Symposium

A Scintillation Counter Symposium under the sponsorship of the I.R.E., the American Institute of Electrical Engineers, the Atomic Energy Commission, and the National Bureau of Standards, will be held in Washington, D. C. on January 26–27, 1954 at the Shoreham Hotel. There will be four sessions covering various aspects of the scintillation counter field: Scintillation Counter Spectrometry, Photomultipliers and Phosphors, General Applications, and Cosmic Ray and High Energy Particle Measurements With Scintillation Counters.

Advance registration is required for attendance. The registration fee is $2.00. Those wishing to attend should forward their application and registration fee to H. O. Wyckoff, Chairman, Attendance Committee, National Bureau of Standards, Washington 25, D. C.

The program is designed, insofar as possible, to present recent advances in scintillation counter technology. The design and performance of instruments and components will be considered. The application of the scintillation counter to the solution of both industrial and purely scientific problems will be discussed. For additional information contact G. A. Morton, Chairman, Scintillation Counter Symposium Committee, RCA Laboratories, Princeton, N. J.

Professional Group News

Broadcast Transmission Systems

The Boston Section of the Professional Group on Broadcast Transmission Systems met on December 3, 1953, at Westinghouse Radio Station WBZ, Boston, Mass., to discuss a Flying Spot Film Scanner for TV.

Members of the Philco Corp. technical staff discussed technical details and applications of the improved film scanner. This unit features excellent picture resolution, color utilization for monochrome film and slides, and ability to operate with all proposed color systems. The talk was very informative.

Ultrasonics Engineering

The Professional Group on Ultrasonics Engineering participated with the Acoustical Society in two sessions on ultrasonics in Cleveland, Ohio, on October 16. This was the second conference within two weeks in which the newly formed Group participated, the first being at the National Electronics Conference in September. One of the two sessions was a round table discussion on Industrial Applications of Ultrasonics with Frank Massa as chairman.

The Group Administrative Committee held its second meeting on October 17 in Cleveland to make plans for the IRE National Convention next March, and the publication of the first Group Transactions in early 1954. To cover the ink and paper expense of such a publication, an assessment of $2 per year will be charged to each member. This assessment will enable paid-up members to receive all Transactions and the Convention Record free of charge. Mr. Julius Bernstein of the Edo Corp. in Long Island, N. Y., has been named as the Group representative on the Convention Record Committee.

New Chapters Approved

At a recent meeting of the Executive Committee of the I.R.E., the formation of the following Professional Group Chapters was unanimously approved: the Los Angeles Section Chapter of the Professional Group on Component Parts; the Philadelphia Section Chapter of the Professional Group on Engineering Management; the Albuquerque-Los Alamos Section Chapter of the Professional Group on Microwave Theory and Techniques; the Chicago Section Chapter of the Professional Group on Microwave Theory and Techniques; and the Chicago Section Chapter of the Professional Group on Radio Telemetry and Remote Control.

The following chapters were also approved: the Albuquerque-Los Alamos Chapters of the Professional Groups on Antennas and Propagation, Circuit Theory, Electronic Computers, and Nuclear Science; the Chicago Chapter of the Professional Group on Electronic Computers; and the Philadelphia Chapter of the Professional Group on Electron Devices.

Professional Group Award Given

At the IRE-RETMA Radio Fall Meeting, the committee appointed for judging Professional Group technical sessions awarded the prize of $100 for the best-sponsored sessions to the Professional Group on Broadcast and Television Receivers.

The Committee of Judges consisted of L. G. Cumming, Chairman, A. G. Jensen, E. I. Anderson, H. F. Dart, and Victor Wouk. The sessions were judged on the following basis: most efficiently run and most interesting sessions, most enthusiastic audience, and best over-all atmosphere indicated by the number and type of questions asked at the conclusion of the papers presented.

Vehicular Communications

The Fourth Annual Meeting of the Professional Group on Vehicular Communications was held at the Somerset Hotel in Boston, Mass., on November 12 and 13, 1953. The theme of this meeting was "Design, Planning and Operation of Mobile Communications Equipment."

The meeting, under the chairmanship of P. R. Kendall, was attended by 221 people. A total of 10 technical papers were presented, and Mr. Kendall had arranged for 10 very interesting exhibits of vehicular equipment.

The papers were highlighted by one presented by Commissioner E. M. Webster of the Federal Communications Commission who discussed new methods of allocations, channel splitting, development of the 450–460 mc band, and equipment standards for vehicular service. A very interesting round table discussion of the papers presented at the three Technical Sessions was held on Friday afternoon, November 13. The technical program was arranged by Waldo Shipman, chairman of the Group. Copies of these papers will be forwarded to all Group members who have paid the usual papers fee.

The Group was fortunate in having Donald S. Leonard, Commissioner of Police, Detroit, Michigan, for the keynote speaker at the luncheon on November 12. The subject of his talk was "Contributions of Vehicular Communications to the Management and Operation of Large Departments." The dinner speaker on November 13 was Saville R. Davis, American News Editor of the *Christian Science Monitor*, who discussed "Engineers and Government: A Study in Communications."

I-R-E News and Radio Notes

Three of I.R.E.'s past Presidents, Dr. A. N. Goldsmith, Dr. Arthur F. Van Dyck, and Raymond Guy, who were among the RCA-NBC original television staff when it was organized in 1928, shown at a recent commemorative meeting in an NBC Studio with others of the original group. Left to right, Don Castle, NBC; Mel Trainer, RCA Victor; Julius Weinberger, Industry Service Laboratory; Dr. A. N. Goldsmith, Consultant; Dr. Arthur F. Van Dyck, RCA; T. A. Smith, RCA Victor; Raymond Guy, NBC; Barton Kreuzer, RCA Victor; and Lester Looney, NBC.

Radio Meteorology Meeting Held

Over the period November 9–12, the University of Texas at Austin was host to some 210 delegates to a technical conference covering the subjects of radar and radio meteorology. This Conference constituted the 125th national meeting of the American Meteorological Society, and was co-sponsored by the I.R.E. through its Professional Group on Antennas and Propagation, the Radar Weather Conference, the International Scientific Radio Union through its National Commission II on Tropospheric Propagation, and the Joint Commission on Radio Meteorology of the International Scientific Unions.

The national and international aspects of the Conference were highlighted by the attendance of delegates from twenty-one states, the District of Columbia, and Hawaii, in addition to those from four Canadian provinces, Japan, England, and New Zealand.

Slightly over one-third of the registrants, a record number for this meeting, were U. S. Weather Bureau personnel. Among the remaining delegates were meteorologists and radio engineers from such groups as University departments of meteorology and electrical engineering, various branches of the Armed Services, private, University, and government research organizations, and commercial aircraft and radio firms.

The Conference proved to be a social as well as a technical success. Two extra-curricular activities were held, the first of which was a social evening at a local hotel at the end of the first day. The second affair was a Texas barbecue held outside of Austin, which provided an enjoyable evening for the nearly two hundred people who attended it.

The technical portions of the Conference were divided into eleven sessions, covering the fields from tropospheric propagation to operational uses of weather radar. Reference should be made to the October 1953 issue of the Proceedings of the I.R.E. or the September issue of the *Bulletin of the American Meteorological Society* for the complete program, including abstracts of the papers.

As a result of the splendid co-operation received from the authors of the sixty odd papers scheduled for presentation at the Conference and the hard work of the personnel of the Bureau of Engineering Research of the University of Texas, copies of the *Proceedings of the Conference on Radio Meteorology* containing long summaries of 80 per cent of the scheduled papers were ready for distribution to registrants on the opening day of the Conference. Additional copies of the Conference *Proceedings* can be obtained from the Bureau of Engineering Research at $3.00 a copy. It is planned to issue a Supplement to the Conference *Proceedings* in the near future which will include long summaries of papers not published in the *Proceedings*, discussion summaries, and other pertinent material.

Engineers Honored at AES Banquet

At the Audio Engineering Society's Fifth Annual Convention held recently in New York City, five members of the I.R.E. were honored for their work in the field of audio engineering.

The Audio Engineering Society Award for service to the Society was bestowed this year upon C. G. McProud, editor and publisher of *Audio Engineering*, and a member of the I.R.E. since 1946.

Fellowships were awarded by the Society to four men, all members of the I.R.E. The recipients were Howard A. Chinn (A'42–SM'45–F'45) chief engineer of the audio-video division of Columbia Broadcasting System's general engineering department; C. J. Lebel (J'25–A'27–M'42–SM'43) secretary of the Society and vice president of Audio Devices, Inc., and Chief engineer of Audio Instrument Co., Inc.; Chester A. Rackey (SM'48) manager of audio-video engineering, National Broadcasting Co.; and H. E. Roys (A'27–SM'47) group manager in the optics, sound, and special engineering section, Engineering Products Department, RCA Victor Division, Radio Corp. of America. The awards were made in recognition of outstanding work in the field of audio engineering.

I-R-E News and Radio Notes

Technical Committee Notes

In the absence of A. G. Jensen the **Standards** Committee convened under M. W. Baldwin, Jr. on October 15th. The first item on the agenda was the consideration of the approved ASA Standard "Method for Determining Flutter Content of Sound Recorders and Reproducers" for publication as an IRE Standard. Dr. A. W. Friend, in order to reacquaint the members present, read through this standard generically, exhibiting the diagrams therein to those present. The committee approved the motion of G. D. O'Neill that the standard be adopted with the deletion of the date, June 1951. There was considerable discussion of the "Proposed Supplement #2 to Standard 51 IRE 17. S1-VHF-UHF Antenna Construction" between Messrs. Avins, Carter, Cady, Ports, Serrell and O'Neill. A number of suggestions were made for changes in wording. R. F. Shea moved for the approval of the supplement with a few minor corrections. There was no further discussion and the motion was carried. This Supplement is now ready for Executive Committee action. The next item was a consideration of the Proposed Definitions of Terms Related to Phototubes (53 IRE 7. S1). After discussing this proposed standard, it was moved by J. G. Kreer and seconded by G. D. O'Neill the complete list be returned to the Electron Devices Committee for clarification of two terms: "Equivalent Noise Input (of a Phototube)" and "Current Amplification (of a Multiplier Phototube)."

The **Antennas and Waveguides** Committee met on October 14th under the chairmanship of D. C. Ports. There was some discussion on the action of the Standards Committee on September 10th regarding this committee's amended definition of "Open Wire Transmission Line." An attempt will be made to have the minutes show that although sentiment was in favor of retaining the original definition, it was finally decided to delete the term entirely. The next item on the agenda was a discussion of the Annual Review Report. The remainder of the meeting was spent in a discussion of Waveguide Component Definitions.

On October 14th the **Audio Techniques** Committee met under the chairmanship of C. A. Cady. One of the items on the agenda was a review of the foreword to be part of the Standards on Audio Techniques: Definitions of Terms, 1953, which was recently approved by the Standards Committee. This preface is necessary before the standard can be submitted to the Executive Committee for approval. H. W. Augustadt unable to attend, wrote proposing a Foreword covering the field of these definitions. A number of suggestions were presented by the committee, and it was decided that the Foreword be referred to Mr. Augustadt with some constructive criticism. Mr. Cady reported that he had been trying to bring the work of the Sound Recording and Reproducing Committee and that of the Audio Techniques Committee into co-operation in order to facilitate the work of both. Joint sponsorship may expedite the completion of this standard.

The **Electron Devices** Committee convened on October 9th under the chairmanship of G. D. O'Neill. Chairman O'Neill reported that the Phototube Definitions have been sent to the Standards Committee for review at their next meeting. The Microwave Tube Definitions will be sent for review to the Standards Committee when they meet in January. (There will be no meeting of the Standards Committee in December.) T. J. Henry, Subcommittee 7.1, reported that no standards work is in progress, but the 1950 standards are being reviewed for possible additions. G. D. O'Neill will act as temporary chairman of Subcommittee 7.2 until a new chairman is appointed, in order to help get out a set of preliminary standards which are being prepared by Subcommittee 7.2.2. E. O. Johnson, chairman of Subcommittee 7.3, stated that Subcommittee 7.3.2 would not be activated until the art was developed somewhat further. Chairman Espersen made the following report on Subcommittee 7.5: Subcommittee 7.5.1 has completed a preliminary draft for Measurements of Nonoperating Characteristics of Microwave Oscillator Tubes which was sent to the Steering Committee for criticism. Subcommittee 7.5.2 has material in preparation for early submission to the Steering Committee. Subcommittee 7.5.3 also has material nearly ready for the Steering Committee. R. M. Ryder discussed the work of subcommittee chairmen in preparing Annual Review material.

Under the Chairmanship of P. J. Herbst the **Radio Transmitters** Committee convened on September 11th. N. B. Tharp of Westinghouse Electric Co. and H. E. Goldstine were presented to the committee as new members. Mr. Goldstine is to replace B. Sheffield as Chairman of Subcommittee 15.2, while he is in Venezuela. T. M. Gluyas was asked for his report on Subcommittee 15.6. His committee is working on "Proposed Standards on Television Transmitters." He stated that his committee had enlarged on the first draft, and now have a second ready for distribution. A section was added to the rough draft submitted last spring. It has four added standards plus a table of contents. A new section—Phase Carriers of Modulated Carriers—has been added. Copies will be submitted to subcommittee members soon. A draft should be able to be submitted to the Main Committee any time after November 1st. Harold Goldberg hopes to present a revised proposal of the "Proposed Standards on Measurements of Pulse Quantities" as soon as the subcommittee resumes work in October. Mr. Sheffield reported as Chairman of Subcommittee 15.2 on the status of "Proposed Methods of Testing Television Transmitters Below 50 Megacycles." Comments have been received from the subcommittee and after these comments have been discussed the document will then be presented to the main committee. This standard should be presented to the Standards Committee this spring. Scopes on Subcommittees 15.2, 15.4 and 15.6 have been received. It was decided that John Ruston have his Subcommittee consider communications relays other than pulse modulated systems. All pulse transmitters and their application are to be reviewed by Dr. Goldberg. T. E. Ahlstedt will act as Chairman of an AdHoc Committee to review FM system.

The **Piezoelectric Crystals** Committee met on October 9th under the chairmanship of Dr. W. P. Mason. A revised copy of the paper, "Methods of Measuring Properties of Piezoelectric Crystals and Electrostrictive Ceramics" by W. P. Mason and H. Jaffe was given final consideration. The paper was approved as amended. A subcommittee was appointed to survey the above named paper and also the paper by E. A. Gerber, "A Review of Methods for Measuring the Constants of Piezoelectric Vibrators" and make recommendations as to which parts should be embodied in the IRE Standard. Another subcommittee was appointed to study the needs for standardization in the fields of ferroelectric crystals and ceramics and to make recommendation of items for embodiment in the IRE Standard.

The **Receivers** Committee convened on October 27th under the chairmanship of Jack Avins. The resignation of L. M. Harris was announced with regret. Mr. Harris has performed very ably as Chairman of the Annual Review Committee of the Receivers Committee and has been responsible for the preparation of the Annual Review Report. R. F. Shea reported on the progress made by Subcommittee 17.4. The sweep radiation standard is now ready for circulation to the Receivers Committee. Good correlation has been obtained between screen-room measurements and interference observed in homes. The results of uhf site calibration tests indicate reasonably good agreement of measurements made on uhf oscillator radiation at various sites. Following a general discussion it was agreed that W. O. Swinyard's Subcommittee 17.8 would have as its primary objective the preparation of a standard on methods of testing color receivers and their revision of the existing standard on monochrome receivers will be delayed.

On October 14th the **Wave Propagation** Committee met under the chairmanship of Dr. Newbern Smith. The Chairman read a letter of resignation from Marion C. Gray. The committee accepted the resignation with regret and unanimously expressed their appreciation for her past participation in their work. Two additional members to the committee, Harold Staras and F. M. Greene, were noted. Dr. C. R. Burrows reported on the status of the Radio Astronomy Definitions. The proposed standard on "Wave Propagation: Methods of Measuring Field Strength" has been on Grand Tour and some comments have been received, all minor in nature. It will be considered for approval in the near future. Although the committee did not see the necessity of an immediate revision of the "1950 Standards on Wave Propagation: Definitions of Terms," the need for certain definitions appeared during the course of the discussions on the radio astronomy definitions.

I-R-E People

Julius G. Aceves (M'40–SM'43) consulting radio engineer and chief engineer for Amy, Aceves & King, Inc., died recently in New York City.

Born in 1888 in Mexico City, Mr. Aceves received his Bachelor's degree in Electrical Engineering from Columbia University in 1910. Following his graduation he took a position with the Physical Laboratory of the Western Electric Co., doing research on measurements on telephonic frequencies of various apparatus, especially in connection with loaded lines.

From 1914 to 1928 he was assistant engineer to Professor M. I. Pupin of Columbia University, working on the design and testing of amplifiers and other static-eliminating circuits and devices. In addition to this work, laboratory instruction, and research on transoceanic cables, Mr. Aceves was also doing personal research work on the operation of receivers from power supply lines.

In October, 1928, he joined Amy, Aceves & King, Inc., to do research and development work on antenna systems, especially the field of noise reduction. For his developments in this field, he was granted several U. S. and foreign patents.

Mr. Aceves was a consulting engineer for other concerns, and the author of several text books used by the International Correspondence School. He was also the author of a chapter on Audio Amplifiers in the Handbook of Radio Engineers.

Robert F. Lewis (A'51) has recently been appointed Vice President of Prodelin, Inc. He was formerly the Technical Director of that organization.

R. F. Lewis

A native of Watertown, N. Y., Mr. Lewis received his Bachelor of Science degree from the Virginia Military Institute, later attending the Wharton School of the University of Pennsylvania and the Stevens Institute of Technology.

Mr. Lewis has been active in the development of antenna systems and transmission lines for many years. He joined the RCA Manufacturing Co. in 1933 and later transferred to their Research Division, where he was engaged in antennas studies until 1939. He worked for the Columbia Broadcasting System on television problems associated with antennas and radio-frequency filters. While serving as a member of the Harvard Radio Research Laboratories he was commissioned as a Major in the Army and placed in charge of the antenna activities of the American British Laboratories in England and on the Continent, during World War II. He was also affiliated with the Federal Telephone and Radio Corp., later transferring to their Telecommunications Laboratories.

He has served on various committees of the Radio-Electronics-Television Manufacturers Association, developing industry standards for antennas and transmission lines for television and telephone applications, and is now a member of their Professional Group on Antennas and Propagation.

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Peter C. Sandretto (A'30–M'40–SM'43) was recently appointed Technical Director of the Federal Telecommunication Laboratories, a division of International Telephone and Telegraph. He was formerly Assistant Technical Director for that organization.

P. C. Sandretto

Mr. Sandretto joined the I. T. and T. Corp. in 1946 and has since served in key executive positions in the field of Aeronautical Radio Engineering, including that of Director of Aviation of the International Telecommunication Laboratories. He was appointed Assistant Technical Director for the FTL in 1948.

Mr. Sandretto received the Bachelor of Science degree in Electrical Engineering from Purdue University in 1930, and the degree of Electrical Engineer in 1938. He also graduated from the Army's Command and Staff School, and performed graduate work at Northwestern University. He has been in the aeronautical radio engineering industry since 1930 when he became a member of the technical staff of Bell Telephone Laboratories. While there, he helped design some of the first radio equipment that was installed on this country's commercial aircraft. In 1932 he joined United Air Lines Transport Corp. and became superintendent of their Communications Laboratories. Under his direction, these Laboratories pioneered in the solution of many aeronautical communications problems such as precipitation static, high-frequency direction finding, instrument approach, and radio altimetry. He held that post until 1942 when he entered the U. S. Air Force. There he served successively as Assistant Chief, Radar Division Headquarters Army Air Forces, Washington, D. C.; U. S. Signals Liaison Officer, Office of the Director-General of Signals, Air Ministry, London; Chief, Electronics Test Section, Headquarters Army Air Force Proving Ground Command, Eglin Field, Florida; and Chief, Electronics Division, U. S. Army Strategic Air Forces. In his last post he was awarded the Bronze Star.

He is the author of many articles on aerial navigation systems, and his book, "Principles of Aeronautical Radio Engineering," is well-known in aviation circles throughout the world. He is a member of Eta Kappa Nu, the Institute of Navigation, the American Institute of Electrical Engineers, and the Armed Forces Communications Association.

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Martial A. Honnell (A'40–SM'47) has been elected Vice President and Chief Engineer of the Measurements Corporation, Boonton, N. J.

M. A. Honnell

Mr. Honnell, who is a former Professor of Electrical Engineering in charge of Communications and Electronics at the Georgia Institute of Technology, has been working in the field of electronics since 1934, when he received his Bachelor of Science degree in Electrical Engineering from that institution.

In 1940 he received the MSEE degree, and in 1945 the degree of Electrical Engineer, both from Georgia Institute of Technology. During World War II, in addition to his duties as Associate Professor at Georgia Tech, he conducted the UHF Techniques Course of the ESMWT Program, and was Supervisor of the Pre-Radar School for Signal Corps employees.

He has done consultant engineering, both on government-sponsored projects and for private industry, in such fields as antennas and propagation, telemetering, television, transmission lines, and electronic instrumentation. He has written and published more than 25 papers on a variety of subjects in the fields of electronics and communications.

Mr. Honnell is a member of the American Institute of Electrical Engineers and of the American Society for Engineering Education. He is also a member of the honorary societies, Tau Beta Pi, Eta Kappa Nu, and Phi Kappa Phi. He is a registered Professional Engineer in Georgia.

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Jerry B. Minter (A'38–VA'39) vice president of the Measurements Corp., Boonton, N. J., and president of the Components Corp., Denville, N. J., has recently been elected president of the Audio Engineering Society.

Mr. Minter has been active in the audio equipment field since his graduation from the Massachusetts Institute of Technology

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in 1934. He was then affiliated with the Boonton Radio Corp. in the development of band-pass intermediate frequency transformers, and in 1936 participated in the development of aircraft radio receivers at the Radio Frequency Laboratories. He then became associated with the late Malcolm P. Ferris, working on the development of a signal generator, a radio noise and field strength meter, and other projects. After the death of Mr. Ferris, Mr. Minter and some associates organized Measurements Corp.


JERRY B. MINTER

A fellow and past president of the Radio Club of America, Mr. Minter is also a member of the Radio Electronics Television Manufacturers Association, the Society of Automotive Engineers, and the American Standards Association. He also helped in the organization of the New Jersey subsection of the I.R.E.

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Floyd A. Timberlake (SM'53) has been recently appointed broadcast field sales representative in RCA Victor's Central Region with headquarters in Chicago.

Mr. Timberlake served as television operations supervisor of the Central Division of the American Broadcasting Co. in Chicago before joining RCA. He is a native of Carthage, Ill., and began broadcast work at Station WCAZ, Carthage, in 1936. He has also been on the engineering staffs of Stations WWAE (now WJOB) and WHIP in Hammond, Ind.; WIND, at Gary, Ind., and WHFC and WEHS, in Chicago. He served for several years as chief engineer for the City of Gary, where he installed the first FM system for the police and fire departments, later joining the Columbia Broadcasting System in Chicago in 1940, where he helped install that network's low-band FM station.

During the war, Mr. Timberlake was a project engineer at the Signal Corps' Evans Signal Laboratory in Belmar, N. J. In 1948 he joined ABC in Chicago in television operations.

Mr. Timberlake is well-known as an amateur radio operator, using the call letters of W9RZP for more than twenty years.

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Robert J. Stahl (J'42–A'43–M'49) has recently joined the Dalmo Victor Co., a San Carlos, Calif. electronics firm, as consulting engineer.

Mr. Stahl was the recipient of the Marconi Memorial Scholarship to the R.C.A. Institutes, which he attended from 1940–1942. In 1942 he joined the Aerolux Light Corp. as an electronics engineer, where he worked until 1944. From 1945 to 1947 he was with the Alabama Power Co., working in the administration of electrical manufacturing in Korea, under the U. S. Military Government. He was later affiliated with the Berkeley Scientific division of Beckman Instruments as chief engineer, after which he was chief engineer with Color Television Inc. until the present time.

In his new position Mr. Stahl will advise on electronics and electro-mechanical problems and on new product development. He will also be in charge of technical phases of patent matters.

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Dean E. Wooldridge (SM'50) and **Simon Ramo** (A'38–SM'44–F'50) have recently announced the organization of the Ramo-Wooldridge Corporation, which will be devoted to research, development, and manufacturing in the general field of advanced electronics and guided missiles.

Mr. Wooldridge, who for the past two years was Vice President in charge of research and development for the Hughes Aircraft Co., Culver City, Calif., is the President of the new organization. He is a graduate of the University of Oklahoma and holds a Ph.D. degree from the California Institute of Technology. Prior to 1946, he was affiliated with the Bell Telephone Laboratories, Inc. for ten years, and during the Second World War was technical head of a section dealing with airborne electronics. He now serves on the Army Ordnance Advisory Committee and the Air Force Armament Advisory Committee.

The Vice President and Executive Director of the new corporation will be Simon Ramo who served for the past several years as Vice President for Operations at the Hughes Aircraft Co. Mr. Ramo received his B.S. in Electrical Engineering from the University of Utah, and, like Mr. Wooldridge, holds his Ph.D. from the California Institute of Technology. From 1936 to 1946 he was a member of the electronics laboratory staff of the General Electric Co. in Schenectady, N. Y. He has served research and development agencies of the military establishments, and the Industry and Education Committee of the Arnold Engineering Development Center of the U. S. Air Force. He is the author of two textbooks on electronics.

Mr. Ramo was the recipient of the Seventh Region IRE Second Annual Achievement Award, presented at the 1953 WESCON, in recognition of his work in the field of electronic and industrial engineering.

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Donald P. Wise (SM'52) has recently joined the staff of the new Worcester, Mass., television station, WWOR-TV, as chief engineer.

Mr. Wise received his engineering education at the Eastern Radio Institute, the Capitol Radio Engineering Institute, and and the Petersham School, Richmond, Surrey, England, where he studied electronics, and radio and television engineering.

Mr. Wise entered the field of broadcasting engineering in 1933 with Radio Station WHDH of Boston and served there as chief engineer until 1941. For the past twelve years, he was chief engineer for the Westinghouse Radio Stations, Inc. WBZ-AM-FM-TV, in Boston, Mass. During World War II he was loaned to the British Army as a commissioned officer in the Signal Corps to work with Royal Electrical and Mechanical Engineers in the radar defense installations of London. During the Korean emergency Mr. Wise was on leave of absence from WRS, Inc. to act as Chief of the Radio Engineering Branch of the Army Signal Section for the Second Continental Army Area. Mr. Wise holds the rank of major in Signal Corps, USAR.

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J. Z. Millar (A'30–SM'45) has been recently appointed Assistant Vice President in charge of development and research of Western Union Telegraph Co.


J. Z. MILLAR

Born in Matton, Ill., on July 3, 1901, Mr. Millar attended the University of Illinois and received the degree of Bachelor of Electrical Engineering in 1923. Following his graduation he joined the Western Union Telegraph Co. as an engineering apprentice. In 1926 he transferred to the Water Mill Laboratory to specialize in electronics. After doing research on short-wave equipment and audio-frequency apparatus for fifteen years, Mr. Millar was called to active duty with the Signal Corps, in which he attained the rank of colonel. He served as a member and director of the Signal Corps Board in Ft. Monmouth, N. J., from 1941–1944, and was then assigned as Signal Officer of the Normandy Base Section and Signal Officer, Loire Section, European Theater.

In 1945, Mr. Millar returned to Western Union and was appointed radio research engineer. In this position he organized the radio research division of the development and research department, and in 1948 helped to establish the world's first radio beam telegraph system. From 1949 until his appointment as Vice President, he held the position of director of research.

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Conrad H. Hoeppner (SM'47) has been appointed manager of the electronics projects department of the W. L. Maxson Corp., New York, N. Y. He will direct research and development on electronic phases of guided missiles, radar, computers, servo-mechanisms, and related systems and equipment.

Before joining Maxson, Mr. Hoeppner was engineering products manager with the Raytheon Mfg. Co. for five years. From 1946

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to 1949 he was director of the electronics laboratory at the Glenn L. Martin Aircraft Co., Middle River, Md., which followed his assignment as senior radio engineer with the Naval Research Laboratory at Anacostia, D. C. While with the Naval Research Laboratory he specialized in guided missiles, beacons, communication security, countermeasures, and digital devices.

Born in Spooner, Wis. in 1918, he received the B.S. and M.S. degrees in electrical engineering from the University of Wisconsin in 1938 and 1939. He attended the Massachusetts Institute of Technology Graduate School as a Tau Beta Pi and M.I.T. fellow, later receiving the degree of professional engineer. During 1942 to 1945 he instructed in electrical engineering and mathematics at George Washington University and at the University of Maryland.

In addition to the 25 patients he holds on pulse circuitry, electronic telemetering, and digital processing equipment, Mr. Hoeppner has authored articles on telemetering.

Mr. Hoeppner is a member of the engineering societies Tau Beta Pi, Eta Kappa Nu, Pi Mu Epsilon, and Sigma Xi.

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John Francis Reintjes (A'41–SM'46) associate professor of electrical engineering at the Massachusetts Institute of Technology, was recently appointed Director of the Servomechanisms Laboratory of the Department of Electrical Engineering at that institution. Professor Reintjes succeeds Professor William M. Pease in this position.

Professor Reintjes was born in Troy, N. Y., in 1912. He attended the La Salle Institute in Troy from 1925–1929, and received the degrees of Electrical Engineer and Master of Electrical Engineering from Rensselaer Polytechnic Institute in 1933 and 1934, respectively.

He first joined the M.I.T. staff in 1943 as a visiting professor of electrical communications in the wartime Radar School. Prior to this date he had been a member of the faculty at Manhattan College in charge of communications engineering courses, and an industrial engineer with the General Motors Corp. Following his two-year term on the staff of the Radar School, Professor Reintjes served as engineer with the General Electric Company's Electronics Laboratory in the field of applied research and development of radar applications. In 1947 he was named assistant professor of electrical engineering at M.I.T., where he has had charge of the educational subjects in the field of radar and contributed to the research in the Research Laboratory of Electronics and Project Lincoln.

While at the Radar School, Professor Reintjes collaborated with other staff members in preparing the manuscript of "Principles of Radar." The two revisions of this book, which is widely recognized as one of the outstanding texts in the radar field, have been the responsibility of Professor Reintjes, with the assistance of Professor Godfrey T. Coate.

Professor Reintjes is an associate member of the American Institute of Electrical Engineers, and a member of the American Society for Engineering Education.

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The retirement of **Charles S. Young** (A'29–VA'39–SM'52), communications engineer of the Pennsylvania Power & Light Co., was recently announced. He is a veteran of over 35 years of service with PP&L.

A native of Johnstown, N. Y., he was graduated from Yale University with a Ph.B. degree in electrical engineering in 1910. That same year Mr. Young became a cadet engineer with the Fulton County Gas & Electric Co., Gloversville, N. Y. Two years later he joined the Northern Indiana Gas & Electric Company, Hammond, Ind., as a construction engineer, becoming assistant superintendent of that company's electrical department in 1913. He moved to Easton in 1915 as superintendent of distribution for Pennsylvania Utilities Co. and in 1917 he joined Electric Bond and Share Co., in New York as an engineer.

Mr. Young joined Lehigh Valley Light & Power, a predecessor company of PP&L, in 1918, as an electrical engineer. In 1920 he was promoted to superintendent of distribution for Pennsylvania Power & Light Co. In 1929 he was named inductive co-ordination engineer and was raised to communications engineer in charge of the communications division of the engineering department in 1945. He took a leading part in the establishment of their radio mobile system. He also was instrumental in the recent major modernization and expansion program of the Palmerton Telephone Co., a subsidiary of PP&L.

Mr. Young is a registered professional engineer in Pennsylvania, and has been chairman of the Middle Atlantic Utility Radio Association.

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Robert B. J. Brunn (A'36–VA'36) a Section Head and Engineering Supervisor of the Hazeltine Electronics Corp., passed away recently.

Mr. Brunn was born in 1911, at Hazleton, Pa. He received the B.S. degree in Electrical Engineering from Lafayette College in 1932 and the M.S. degree from the Massachusetts Institute of Technology in 1933.

He joined Hazeltine Electronics Corp. in 1936, engaging in research and development work on broadcast receivers. He joined the group working on television problems in 1938. During the period from 1939–1941, he was concerned with development and testing of television and sound receivers.

During World War II, Mr. Brunn was instrumental in the design of the very complex airborne IFF equipments. Following the war, Mr. Brunn was responsible to a major degree for the development of the first operable Distance Measuring Equipment for air navigation and traffic control. He had the major responsibility for the design of the DME ground beacons installed throughout the United States by the CAA. Mr. Brunn was also primarily responsible for the conception of the first reliable airborne DME interrogator-responser and directed the development of this project to the production of successful equipment.

Mr. Brunn had six United States Patents issued to him in the course of his work. He was a member of Phi Beta Kappa and the American Institute of Electrical Engineers.

Books

Modulation Theory by Harold S. Black

Published (1953) by D. Van Nostrand Company, Inc., 250 Fourth Ave., New York 3, N. Y., and D. Van Nostrand Ltd., 25 Hollinger Road, Toronto, Ont., Canada. 345 pages+11-page index+6-page appendix +xi pages. 20 figures and 5 plates. 6×9¼. $8.75.

Harold S. Black is a member of the Technica Staff of Bell Telephone Laboratories, Inc.

This book, a new addition to the Bell Laboratories Series, discusses fundamentals of modulation in the light of recent developments in information theory. The new concepts developed by Shannon, Wiener, and others are given in concise form, providing the basis for non-surpassable ideals in information handling. Comparison of systems is made from the standpoint of redundancy, bandwidth occupancy, threshold effects, rate of receiving information, signal to noise ratio, distortion, delay, inter-channel interference and probability of errors.

In the first eight chapters, the basic concepts are described and treated analytically. The sampling principle, quantization, code transmission, and multiplexing, lead to Chapter 6, dealing with efficient systems of communication. Here, Shannon's theorem $C=B \log_2 (1+S/N)$ is used to show how bandwidth may be exchanged for signal power. The meaning and measure of information is discussed in relation to efficient coding, channel capacity and equivocation. Existing systems are then compared with the ideal.

Speed of signaling and channel capacity are discussed in Chapter 7. Signaling at the Nyquist rate in the presence of noise is compared with Shannon's ideal and is shown to require somewhat more power, for example, about 8 db for a frequency of error of 10^{-5}. Chapter 8 concludes the information theory discussion with a treatment of the reduction of signal power through the use of redundant codes. A small reduction is shown to be possible by using error checking and correcting methods as proposed by Hamming.

The remaining 12 chapters discuss in considerable mathematical detail the various types of modulation, modulators, demodulators and effects of noise and interference. Design techniques, methods of instrumentation and specific applications are not included in this discussion. However, the theoretical aspects of the modulation field are well covered and provide the advanced engineer with an up-to-date treatise. A knowledge of elementary calculus and Fourier methods are needed for a complete understanding of the text. The references are extensive and review questions are included which are of value for further study in this field.

B. A. Trevor
RCA Laboratories Division
Princeton, N. J.

Luminescence and the Scintillation Counter by S. C. Curran

Published (1953) by Academic Press, Inc., 125 East 23rd St., New York, N. Y., and Butterworth's Scientific Publications, London, England. 207 pages +11-page index+x pages. 93 figures. 5½×8¾. $5.80.

People working with scintillation counters have long been handicapped by the absence of any comprehensive treatment on the subject. This book gives a short treatment of all aspects of luminescence and scintillation counting. No one person can be an authority on the whole subject. Thus the author follows more or less closely published books or articles in each field treated. In cases where contradictory results have been published, the author has attempted to present both sides.

After a general introduction in the first chapter, the second chapter of the book gives a short summary of the interaction of radiation with matter. The next three chapters are devoted to the phenomenon of secondary emission, commercial photomultipliers and their performance. This is followed by two chapters on the general theory of luminescence and fluorescence. The next two chapters are devoted to the preparation and performance of specific scintillation crystals and liquids. The remaining three chapters deal with general applications and associated electronic circuits. The reviewer was somewhat disappointed that relatively little attention was given to practical applications. For instance, absolute or relative detection efficiencies of gamma rays of different energies are discussed only in qualitative terms. However, it was not the intention of the author to discuss "in detail the almost unlimited number of particular applications of the scintillation method."

The field of scintillation counting is still developing very rapidly. Therefore, the reader will appreciate that the book is up-to-date as regards published material. However, even since publication of the book a number of new developments have occurred in this field.

In general this book should prove very useful to workers in the field by giving valuable references. To a novice the book gives a good general introduction. Only calculus is required to understand the equations given in the text.

Alois W. Schardt
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The Annual Index of these Abstracts and References, covering those published in the PROC. I.R.E. from February 1952, through January 1953 is now out of print. No further orders will be accepted.

The number in heavy type at the upper left of each Abstract is its Universal Decimal Classification number and is not to be confused with the Decimal Classification used by the United States National Bureau of Standards. The number in heavy type at the rop right is the serial number of the Abstract. DC numbers marked with a dagger †) must be regarded as provisional.

ACOUSTICS AND AUDIO FREQUENCIES

534.141+534.143:534.322.1 **3461**
The Relations between Electrical and Mechanical Production of Musical Sounds. The Question of Tone-Colour Interval Circles—R. Bierl. (*Z. angew. Phys.*, vol. 5, pp. 231–237; June, 1953.)

534.15 **3462**
Study and Representation of a Complex Musical Tone—A. Moles (*Funk u. Ton*, vol. 7, pp. 277–287; June, 1953.) German version of 1219 of May.

534.24:526.956.5 **3463**
Reflection of Sound in the Ocean from Temperature Changes—R. R. Carhart. (*Jour. Appl. Phys.*, vol. 24, pp. 929–934; July, 1953.) Coefficients r and r' for "sharp" and "smooth" reflection are distinguished, according as the thickness of the layer in which a velocity change occurs is or is not negligible. Theory for the two cases is developed and values of r and r' as functions of angle of incidence corresponding to practical conditions are calculated.

534.6:621.395.625.3 **3464**
Storage Methods of Sound Measurement—H. Etzold. (*Funk u. Ton*, vol. 7, pp. 307–315; June, 1953.) Equipment is described which uses an A.E.G. Type-KL15 magnetophone as the storage unit. Details are given of the means adopted for providing a linear decibel scale for the intensity of the recorded sounds.

534.833.4 **3465**
Absorption Coefficient of Acoustic Materials—R. Lamoral. (*Onde élect.*, vol. 33, pp. 461–467; July, 1953.) Values of the absorption coefficient α of two materials were determined from reverberation-time measurements, using Sabine's formula. The frequencies used ranged from 125 cps to 4 kc. The results obtained for samples of different surface area, or for samples of the same total area consisting of various numbers of separate pieces, differ so much that comparison between the values of α for different materials can only be reliable if the necessary measurements are carried out under specified conditions.

534.833.4 **3466**
Testing Sound-Absorbing Materials in a Reverberating Room—B. D. Tartakovski and M. M. Efrussi. (*Compt Rend. Acad. Sci. U.R.S.S.*, vol. 82, pp. 373–376; Jan. 21, 1951. In Russian.)

534.84 **3467**
Collation of the Reverberation Times of Berlin Sound-Recording Studios and Auditoria—H. Dippner and H. J. Zemke. (*Frequenz*, vol. 7, pp. 71–81; March, 1953.) Measurements have been made in churches, concert halls, film theatres and studios. Reverberation-time/frequency curves are shown with details of the size and seating capacity for each of the 52 cases dealt with, and many photographs of interiors.

534.84:534.861.1:621.396.712.3 **3468**
Architectural Acoustics of the Cologne Broadcasting Centre—L. Muller. (*Tech. Hausmitt. NordwDtsch. Rdfunks*, vol. 5, pp. 87–97; 1953.) A detailed account, with numerous illustrations, is given of the treatment of the floors, walls and ceilings of the various studios to obtain acoustical characteristics suitable for the differing requirements for chamber music, full orchestra or organ, speech, dance music, etc. Methods of acoustic damping in the foyer and corridors, by means of absorbing materials, resonators and diffusers of various types, are also described.

621.395.623.7:534.843 **3469**
The Loudspeaker in the Home—P. J. Walker. (*Jour. Brit. IRE*, vol. 13, pp. 377–380; July, 1953.) A nonmathematical discussion of the problems of sound reproduction in relation to the acoustics of ordinary rooms. The concept of the ideal headphone is introduced and its limitations are indicated.

621.395.623.8 **3470**
Public-Address Systems in Generating Plants—Bartlett. (*Trans. AIEE*, vol. 70, part II, pp. 1804–1810; 1951.) For another account see 615 of March.

621.395.625.3 **3471**
Studies on Magnetic Recording: Part 1—Introduction—W. K. Westmijze. (*Philips Res. Rep.*, vol. 8, pp. 148–157; April, 1953.) A survey of the principles and historical development of methods of magnetic recording.

ANTENNAS AND TRANSMISSION LINES

621.315.212:621.315.615 **3472**
Liquid-Dielectric Radiofrequency Coaxial Cables—R. M. Soria, C. C. Camillo and J. G. Krisilas. (*Proc. NEC*, vol. 8, pp. 469–480; 1952.) An account is given of research in connection with the development of flexible coaxial cables using a liquid dielectric, driven through the cable under pressure, to obtain increased heat dissipation. Mineral oil and a silicone oil were found suitable. The results obtained show that a cable of the liquid-dielectric type can be constructed to operate with an input power 8 times that for the equivalent standard RG cable, and with satisfactory operation at high ambient temperatures and high altitudes.

621.392.09 **3473**
Surface-Wave Propagation over a Coated Conductor with Small Cylindrical Curvature in Direction of Travel—K. Horiuchi. (*Jour. Appl. Phys.*, vol. 24, pp. 961–962; July, 1953.) Analysis indicates departures to be expected from the results obtained for a plane conductor [2097 of 1951 (Attwood)]. The effect of a bend in a surface-wave transmission line is to produce attenuation and to increase the field intensity on the outside of the bend.

621.392.21:621.317.343 **3474**
Characteristic Impedance of Rectangular Coaxial Transmission Lines—Y. A. Omar and C. F. Miller. (*Trans. AIEE*, vol. 71, part I, pp. 81–89; 1952.) The characteristic impedance of several coaxial rectangular transmission lines was measured by a standing-wave method at about 430 mc. The results obtained enabled a relation between line dimensions and characteristic impedance to be developed from that for confocal elliptical lines.

621.392.21.017 **3475**
Effect of Losses in H. F. Transmission Lines—S. Albagli. (*Onde élect.*, vol. 33, pp. 270–273; June, 1953.) In transmission-line calculations where it is necessary to take account of losses, it is often assumed that the characteristic impedance is real. This is admissible as a first approximation, but it can lead to considerable errors in certain cases. To the second approximation the characteristic impedance is real only if the metal and dielectric loss coefficients are equal. Comparison is made between results obtained on this supposition and those obtained on the assumption that dielectric losses are negligible. In some cases the results differ by 100 per cent.

621.392.211 **3476**
Propagation of Electromagnetic Waves along an Infinite Helical Slit—S. A. Vakin. (*Compt. Rend. Acad. Sci. U.R.S.S.*, vol. 84, pp. 37–40; May 1, 1952. In Russian.) The field, inside and outside the cylindrical surface containing the slit, is determined by assuming a particular distribution of potential along the slit. A transcendental equation for the propagation constant, is derived and solved for four particular values of δ, the helix pitch angle. The retardation of the wave, τ, which is a function of the propagation constant, is ~ 1 over a

range of values of r_0, the radius of the cylinder. This theoretical result was confirmed experimentally.

621.392.26 3477
Matching Discontinuities in Waveguides—J. C. Parr. (*Wireless Eng.*, vol. 30, pp. 243–249; Oct. 1, 1953.) Simple systematic procedure is described for matching both waveguide measuring equipment and other waveguide sections. The technique of four-screw tuning is used, and theory is outlined to show how it is possible to obtain any desired value of reflection factor. The different requirements for matching terminating sections, insertion devices or generators are discussed. Modifications appropriate for cases of large mismatch are indicated. The distance between tuning screws should be the smallest convenient multiple of $\lambda/8$.

621.392.43:621.396.67 3478
A Solution for a Practically Frequency-Independent Transition between a H.F. Coaxial Cable and a Balanced H.F. Transmission Line—H. Graziadeí. (*Fernmeldetech. Z.*, vol. 6, pp. 311–319; July, 1953.) Feeder arrangements for rhombic transmitter antennas are considered. The theory of a wide-band unbalance/balance impedance-matching transformer is given; design and applications are considered. A transformer consisting of a reactive loop and an exponential line in parallel with the output of a coaxial line has been designed to give a nearly level response over the 10-60-m band for a 60 Ω/500Ω line impedance ratio.

621.396.67 3479
Polystyrene and Lucite Rod Antennas— G. von Trentini. (*Jour. Appl. Phys.*, vol. 24, pp. 960–961; July, 1953.) Measurements were made with tapered rods thinner than those used by Horton and McKinney (1204 of 1952); values of gain obtained were somewhat higher and effects due to dielectric losses less accentuated.

621.396.67.012.71 3480
V.H.F. Aerial Radiation Pattern Measurements—E. G. Hamer. (*Electronic Eng.*, vol. 25, pp. 427–431; Oct., 1953.) Various measurement techniques are discussed and an indication is given of conditions to be satisfied to obtain polar diagrams free from errors due to induction fields, surface wave and variation of Brewster angle. Automatic machines for plotting radiation patterns are described.

621.396.674 3481
Loop Aerials for Portable Broadcast Receivers—E. G. Beard. (*Philips Tech. Commun.*, (*Australia*) pp. 16–18; 1953.) Theoretical considerations lead to a suggested design in which a small loop antenna is surrounded by a number of co-planar closed metallic loops, the induced emf's in which are all transferred to the central antenna, thus giving high efficiency.

621.396.677 3482
Radiation Conductance of Axial and Transverse Slots in Cylinders of Elliptical Cross Section—J. Y. Wong. (PROC. I.R.E., vol. 41, pp. 1172–1177; Oct., 1953.) Formulas and graphs are presented for the radiation field and the radiation conductance. The degree of curvature of the cylinder surface has a considerable influence on the radiation conductance for the transverse slot.

621.396.677 3483
Grids as Circuit Elements for Electromagnetic Waves in Space—G. von Trentini. (*Z. angew. Phys.* vol. 5, pp. 221–231; June, 1953.) An account of experimental investigations of the characteristics of grid lenses similar to that previously described (937 of April), but using different types of grid-wire loading.

621.396.677 3484
Microwave Wide-Angle Scanner—J. Brown. (*Wireless Eng.*, vol. 30, pp. 250–255; Oct., 1953.) A study is made of microwave lenses of the type comprising a sphere whose refractive index varies with distance from the center. In previously described lenses of this type [e.g. 2723 of 1950 (Jones)] scanning is performed by moving the feed over the lens surface. Mechanical problems can be simplified by arranging for the feed to move on a smaller sphere concentric with the lens. A suitable law is derived for the variation of refractive index in this case.

621.396.677 3485
Experimental Verification of the Metal-Strip Delay-Lens Theory—S. B. Cohn. (*Jour. Appl. Phys.*, vol. 24, pp. 839–841; July, 1953.) Measurements made on five metal-strip delay structures, three in the form of waveguide elements and two free-space arrays, are described. Only one of four suggested formulas for refractive index is in good agreement with experiment over the full practical range. This is based on a transmission-line equivalent circuit taking proximity effects into account.

621.396.677 3486
Excitation and Radiation Properties of Microwave Lenses—K. Hurrle. (*Fernmeldetech. Z.*, vol. 6, pp. 332–337; July, 1953.) The conditions for the optimum excitation of a lens and the resulting radiation pattern are derived. Experimental results are given for a dielectric lens and a path-length lens [3058 of 1949 (Kock)] operating at a wavelength of 6.1 cm.

621.396.677:535.326:621.317.3 3487
Microwave Measurements on Metallic Delay Media—(*See* 3652.)

621.396.677.011.21 3488
Input Impedance of Folded-Dipole Antennas—R. E. Beam and P. Andris. (*Proc. NEC.*, vol. 8, pp. 678–691; 1952.) A general expression for the input impedance is derived in terms of the self-and mutual-radiation impedances and transmission-line impedances of the two conductors forming the folded dipole. Integral-equation methods are used to determine approximate values of the radiation impedances for sinusoidal current distribution. Experimental and theoretical curves representing the resistive and reactive components of the input impedance as functions of frequency are given for two folded dipoles, one with both conductors of $\frac{7}{8}$-inch Cu tube and the other with fed elements of $\frac{3}{8}$-inch tube, the rest being $\frac{7}{8}$-inch. In some cases the gap capacitance at the feed point was taken into account in the calculations.

621.396.677.029.63 3489
Helical-Beam Antenna Performance—E. F. Harris. (*Commun. Eng.*, vol. 13, pp. 19–20, 45; July/Aug., 1953.) Helical antennas for wide-band point-to-point radio communication in the 450–470-mc 890–960-mc and 1.75–2.11-kmc bands are described and design details given. The antenna gains are 13, 16.5 and 20 db respectively, using a single helix, two helices or four helices. If helices of opposite sense are used for transmission and reception, a discrimination of about 20 db is obtained between the direct beam and the ground-reflected beam.

621.396.677.1:523.72:621.396.822 3490
New Techniques in Radio Astronomy—J. D. Kraus and E. Ksiazek. (*Electronics*, vol. 26, pp. 148–152; Sept., 1953.) A broadside array of 24 pairs of helical antennas with axes parallel, mounted on a pivoted ground screen, has been installed at the Ohio State University. Each helix is 10 feet long, 15 inches in diameter, and has 10 turns. A beam width of 1.2 degrees is obtained at 250 mc. The receiving equipment is described and typical records are shown.

621.396.677.5:621.3.042.12 3491
The Receiving Loop with a Hollow Prolate Spheroidal Core—J. R. Wait. (*Canad. Jour. Tech.*, vol. 31, pp. 132–137; June, 1953.) The case of a loop with a solid spheroidal core has previously been considered (1917 of July). The relative gain is calculated for a loop wound symmetrically round the centre of a hollow shell of ferromagnetic material with permeability μ of 20, 50, 200 and 500. Neglecting core losses, a hollow core of moderate length is more efficient than a solid core of the same mass, particularly for high values of μ.

CIRCUITS AND CIRCUIT ELEMENTS

621.3(083.74) 3492
The Standardization of Symbols and the Arrangement of Electronic Circuit Diagrams—L. H. Bainbridge-Bell. (*Jour. Brit. IRE.*, vol. 13, pp. 339–347; July, 1953. Discussion, pp. 347–353.) Arrangement of circuit diagrams to give a clear indication of the operation is advocated.

621.3.011.22.025 3493
Realization of Alternating-Current Resistance—U. Kirschner. (*Funk u. Ton*, vol. 7, pp. 298–306; June, 1953.) Methods of realizing resistance functions by arrangements of the partial-fractions or the continued-fractions type are described. Possible arrangements are shown in two tables.

621.3.012.11 3494
Geometrical Transformation of Impedance Diagrams—H. Briner and W. Graffunder. In 2576 of October please change the last word in the abstract to "described."

621.3.066.6 3495
The Effect of Inductance on Fine Transfer between Platinum Contacts—J. Warham. (*Proc. IEE*, part I, vol. 100, pp. 163–168; July, 1953.) An investigation was made with Pt contacts in a 6-v circuit breaking currents of the order of 1 amp; the circuit inductance was varied from 0.05 to 10 μH. Measurements of the volume transferred and examination of the surface structure indicate that there are two types of transfer; (*a*) true bridge transfer, independent of inductance, and (*b*) short-arc transfer, dependent on the inductance.

621.3.066.6 3496
The Behaviour of Metallic Contacts at Low Voltages in Adverse Environments—A. Fairweather. (*Proc. IEE*, part I, vol. 100, pp. 174–182; July, 1953.) The problem discussed is that of obtaining a metal-to-metal contact mechanically when the contacts are contaminated by dust or grease or are coated with films produced by adsorption, tarnishing or corrosion. Various types of contact are considered. Principles are outlined which provide a basis for design and testing; a new technique is described for the continuous dry lubrication of sliding contacts in mechanical and electrical systems.

621.3.066.6:621.314.58 3497
Long-Life Contacts for Unidirectional Currents of 1–20 Amperes—A. L. Allen. (*Proc. IEE*, part I, vol. 100, pp. 158–162; July, 1953.) An experimental investigation was made of fundamental physical phenomena concerned in the operation of contacts in vibratory converters; the influence of voltage and current on the direction of migration of material was studied. Long life was obtainable with Pt contacts or with contacts of dissimilar metals, but on heavy duty an adequate life was obtained only with w contacts in a low-oxygen atmosphere.

621.3.066.6:621.396.822 3498
Noise of Metal Contacts—F. A. P. M. Theunissen. (*Appl. Sci. Res.*, vol. B3, pp. 201–208; 1953.) Measurements were made of the small voltage fluctuation produced by the passage of direct current through ball contacts.

Current values from 1 to about 50 m were used, and the influence of contact resistance pressure and temperature was investigated, for steel, copper and gold contacts. A possible mechanism accounting for the results is suggested.

621.314.2 3499
Design of Unequal-Q Double-Tuned Transformers—S. Deutsch. (*Trans. AIEE*, vol. 71, part I, pp. 314–320; 1952.) Equations and design curves are given which should simplify calculations of certain of the transformer characteristics.

621.314.22.015.7 3500
A Turns Index for Pulse Transformer Design—H. W. Lord. (*Trans. AIEE*, vol. 71, pp. 165–168; 1952.) Full paper. See 1250 of May.

621.314.222:621.314.6 3501
Transient Conditions in a Transformer Supplying Energy to a Half-Wave Rectifier Circuit—P. N. Martin. (*Trans. AIEE*, vol. 70, part II, pp. 1468–1479; 1951.) Analysis is given for a simplified equivalent circuit, leakage reactance and core loss being neglected. Experimental results confirm the theory.

621.314.263 3502
The Magnetic-Cross Valve—H. J. McCreary. (*Trans. AIEE*, vol. 70, part II, pp. 1868–1874; 1951. Discussion, pp. 1874–1875.) Further details are given of the device previously described (2727 of 1950) and of its practical applications, with circuit diagrams and illustrations of the "power ringers" converting 60-cps power to 30 cps and 20 cps respectively.

621.314.3† 3503
On the Mechanics of Magnetic-Amplifier Operation—R. A. Ramey. (*Trans. AIEE*, vol. 70, part II, pp. 1214–1222; 1951. Discussion, pp. 1222–1223.)

621.314.3† 3504
Magnetic Amplifiers of the Balance Detector Type—their Basic Principles, Characteristics, and Applications—W. A. Geyger. (*Trans. AIEE*, vol. 70, part II, pp. 1707–1718; 1951. Discussion, pp. 1718–1720.)

621.314.3† 3505
Predetermination of Control Characteristics of Half-Wave Self-Saturated Magnetic Amplifiers—H. Lehmann. (*Trans. AIEE*, vol. 70, part II, pp. 2097–2103; 1951. Discussion, p. 2103.)

621.314.3† 3506
Bibliography of Magnetic Amplifier Devices and the Saturable-Reactor Art—J. G. Miles. (*Trans. AIEE*, vol. 70, part II, pp. 2104–2123; 1951.) A very comprehensive bibliography of 901 published books, articles, and patents, for the period 1887 to mid-1951.

621.314.3† 3507
On the Control of Magnetic Amplifiers—R. A. Ramey. (*Trans. AIEE*, vol. 70, part II, pp. 2124–2128; 1951.)

621.314.3† 3508
Steady-State and Transient Analysis of an Idealized Series-Connected Magnetic Amplifier—L. A. Pipes. (*Trans. AIEE*, vol. 70, part II, pp. 2129–2133; 1951. Discussion, pp. 2133–2135.)

621.314.3† 3509
Series-Connected Magnetic Amplifier with Inductive Loading—T. G. Wilson. (*Trans. AIEE*, vol. 71, part I, pp. 101–110; 1952.) Full paper. See 338 of February.

621.314.3† 3510
The Effective Feedback Ratio of Magnetic Amplifiers—L. A. Finzi, G. F. Pittman, Jr, and H. L. Durand. (*Trans. AIEE*, vol. 71, part I, pp. 157–164; 1952.)

621.314.3† 3511
Magnetic Amplifiers of the Self-Balancing Potentiometer Type—W. A. Geyger. (*Trans. AIEE*, vol. 71, part I, pp. 383–395; 1952.) For a digest see *Elect. Eng.*, vol. 72, p. 294; April, 1953.

621.314.3† 3512
High-Speed Magnetic Amplifier—L. J. Johnson. (*Elect. Mfg*, vol. 50, pp. 98–101, 324; Nov., 1952.)

621.314.7:621.3.015.3 3513
Transient Analysis of Junction Transistor Amplifiers—W. F. Chow and J. J. Suran. (Proc. I.R.E., vol. 41, pp. 1125–1129; Oct., 1953.) In analyzing transistor operation, transit-time effects must be taken into account; this can be done to a sufficiently close degree of approximation by including in the equivalent circuit an *rc* network in series with an idealized delay line. Only simple Laplace transforms are then involved in the response calculations. The theory is supported by experimental results.

621.314.7:621.3.015.7 3514
Pulse Response of Junction Transistors—N. H. Enestein and M. E. McMahon. (*Trans. IRE*, pp. 5–8; June, 1953.) The case of low load resistance is considered theoretically and experimental results are shown graphically. The response characteristics are discussed. Good qualitative and fair quantitative agreement was found between predicted characteristics and those determined from pulse and ac measurements.

621.314.7:621.318.57 3515
The Phase-Bistable Transistor Circuit—R. H. Baker, I. L. Lebow, R. H. Rediker, and I. S. Reed. (Proc. I.R.E., vol. 41, pp. 1119–1124; Oct., 1953.) Properties of transistor switching circuits are discussed. A unit is described which comprises a commutating ring of two transistors each connected as a one-shot multivibrator, the two being alternately triggered by a series of clock pulses. The arrangement is used in a binary counter, with a clock-pulse frequency of 500 kc.

621.314.7:621.318.57 3516
A Transistors in Trigger Circuits—S. Walter. (Proc. I.R.E., vol. 41, p. 1190; Oct., 1953.) A simple circuit using a single transistor is described.

621.314.7:621.396.615.029.3 3517
Low-Distortion Transistor Audio Oscillator—P. G. Sulzer. (*Electronics*, vol. 26, pp. 171–173; Sept., 1953.) Design details of an oscillator operating at any one of the four frequencies 20, 200, 2000 and 20000 cps, and including 3 *p-n-p* junction transistors. Series resistors are used to stabilize emitter currents, and a tungsten-filament lamp to control amplitude. Maximum available output is 1 v. The low-noise characteristics are ascribed to the very narrow operating bandwidth.

621.314.7:621.396.645 3518
The Common-Collector Transistor Amplifier at Carrier Frequencies—F. R. Stansel. (Proc. I.R.E., vol. 41, pp. 1096–1102; Oct., 1953.) Formulas are derived for the af operating parameters of the grounded-collector ("common-collector") circuit. The variation of the transistor current-amplification factor α with frequency is investigated. The effect of operating conditions on the cut-off frequency f_c (i.e. the frequency at which α drops to $1/\sqrt{2}$ of its af value) is discussed. Modified formulas are hence derived which are valid up to about $2f_c$. Experimental results support the theory presented. Point-contact, *n-p-n*-junction and early *p-n-p*-alloy transistors were studied.

621.314.7:621.396.645 3519
Complementary-Symmetry Transistor Circuits—R. D. Lohman. (*Electronics*, vol. 26, pp. 140–143; Sept., 1953.) Under normal bias conditions, the current which flows in each lead to an electrode of a *p-n-p*-transistor is the negative of the corresponding current in an *n-p-n* transistor, this is termed static symmetry. The polarity of an input signal that will increase conduction in a *p-n-p* transistor is the opposite of that for an *n-p-n* transistor; this is termed dynamic symmetry. Circuits are described that use (*a*) static symmetry, (*b*) dynamic symmetry, (*c*) both types of symmetry. These include a stabilized direct-coupled class =A amplifier with a voltage gain of 660, a pulse circuit which converts a 0.25-v half-sine-wave to 20-v pulses, a class-B power output circuit using four transistors with overall feedback and giving a gain of about 30 db when working into a 16-Ω load, and a television vertical-deflection system with a class-B output stage connected directly to the deflection yoke. See also 2583 of September (Sziklai).

621.314.7:621.396.645 3520
Transistor Theory and Transistor Circuits—H. E. Hollmann. (*Arch. elekt. Übertragüng*, vol. 7, pp. 315–327; July, 1953.) Simple theory for transistors is developed from that for thermionic valves on the basis of the duality principle and by comparison with the aperiodic retarding-field valve. Semidynamic rather than static characteristics are obtained, by biasing the collector by means of a resistor. These characteristics can be converted to the usual static ones by a co-ordinate transformation. Parameters are measured by means of a transistor bridge equivalent to that used for obtaining the dynamic characteristics of a thermionic valve. The parameters found are related to the constant-current values of the parameters hiterto used. Simple formulas are derived for the voltage and power amplification of grounded-base and grounded-emitter circuits. Use of the negative static resistance of a grounded-emitter transistor for measuring the resonance resistance of oscillatory circuits is discussed.

621.314.7:621.396.645.36.029.4 3521
Push-Pull Transistor Amplifiers—J. I. Missen. (*Wireless World*, vol. 59, pp. 467–470; Oct., 1953.) A description is given of a practical af power amplifier using point-contact transistors and developed from the class-B thermionic-valve amplifier by application of the duality principle. This amplifier can deliver >400 mw at <10 per cent harmonic distortion.

621.314.7.012.8 3522
Equivalent-Circuit Diagrams of the Transistor—W. Klein. (*Frequenz*, vol. 7, pp. 59–60; March, 1953.) Different representations for transistors are derived from the equivalent circuit of the nonreversible quadripole (3031 of 1952):—(*a*) a two-tube circuit; (*b*) a one-tube circuit with a lossless transformer.

621.314.7.012.8 3523
Transistors: Theory and Application: Part 7—Equivalent Transistor Circuits and Equations—A. Coblenz and H. L. Owens. (*Electronics*, vol. 26, pp. 156–161; Sept., 1953.) Relations between transistor parameters, circuit elements and performance are derived by application of Kirchhoff's mesh equations for the transistor equivalent circut. Part 6: 3444 of November.

621.316.726.078.3 3524
Theory of A.F.C. Synchronization—W. J. Gruen. (Proc. I.R.E., vol. 41, p. 1171; Oct., 1953.) Correction to paper noted in 3214 of November.

621.316.84:539.23]:621.317.727.029.63 3525
Fabrication of Radio-Frequency Micropotentiometer Resistance Elements—L. F. Behrent. (*Jour. Res. Nat. Bur. Stand.*, vol. 51, pp. 1–9; July, 1953.) Stable low-resistance disk-type resistors are required for the Bureau of Standards rf micropotentiometer previously

described (1712 of 1951). Various processes for forming thin-film resistors are considered. Three methods are described by which it is possible to produce resistors stable to within ±1 per cent, viz., (*a*) high-temperature firing, (*b*) evaporating and plating, (*c*) use of disks cut from sheets of carbon film deposited on bakelite. A chemical-reduction process is under investigation.

621.318.4 3526
Copper Eddy-Current Losses in Coils with Carbonyl-Iron and Ferrite Cores.—J. Brackmann and J. Frey. (*Frequenz*, vol. 7, pp. 185–191; July, 1953.) The design of low-loss short multilayer coils and long single-layer coils is considered. Because core losses are much reduced with modern ferrite cores, the relative importance of the copper eddy-current losses is greater. These losses and their dependence on the coil and core parameters are discussed in detail.

621.318.435 3527
Saturable Reactors with Inductive D.C. Load: Part 1—Steady-State Operation—H. F. Storm. (*Trans. IEE*, vol. 71, part I, pp. 335–343; 1952.)

621.319.45:539.23:537.311.33 3528
Distribution of Conductivity within Dielectric Films on Aluminum—J. E. Lilienfeld and C. Miller. (*Jour. Electrochem. Soc.*, vol. 100, pp. 222–226; May, 1953.) Frequency and formation-voltage characteristics were determined for a capacitor with an anodized Al anode, Al cathodes and electrolyte consisting of boric acid and borates, in the range 20 cps–10 kc. An equivalent circuit is given and a model is suggested consisting of a 2-layer dielectric film, one layer, adjacent to the metal surface, having low conductivity, lower loss, independent of frequency, but dependent on the peak formation voltage, the other film with opposite properties.

621.385.3:621.392.5 3529
Triode Transformation Groups—A. W. Keen. (*Wireless Eng.*, vol. 30, pp. 238–243; Oct., 1953.) The properties of the six networks including respectively the six possible transmission paths through a triode valve (1321 of 1951) are shown to be interrelated in such a way that, given the characteristics of any one of the circuits, those of the remainder are obtainable by a routine transformation process.

621.392 3530
Potential Analog Network Synthesis for Arbitrary Loss Functions—E. S. Kuh. (*Jour. Appl. Phys.*, vol. 24, pp. 897–902; July, 1953.) A method of network design is described in which the appropriate potential problem is formulated on the basis of a given loss function by introducing continuous charge distribution on the complex-frequency plane. The technique of charge quantization is used to find the natural modes of the network function.

621.392.012 3531
Feedback Theory—Some Properties of Signal Flow Graphs—S. J. Mason. (Proc. I.R.E., vol. 41, pp. 1144–1156; Oct., 1953.) The equations characterizing transmission systems may be represented by networks of directed branches, termed "signal-flow graphs"; the branches terminate at nodes, which represent repeater stations. The topology of these diagrams is studied with particular reference to feedback circuits. The technique is illustrated by application to specific circuit design problems.

621.392.4 3532
Two Theorems on Two-Terminal Electrical Networks—F. Reza. (*Compt. Rend. Acad. Sci.*, (Paris), vol. 237, pp. 429–430; Aug., 1953.) Given that the impedance of the network is a rational function $Z(S)$ of the complex frequency S, and putting $Z(S)=P(S)/Q(S)$, it is shown that

$$Z^n(S)=\frac{d^{n}P(S)/dS^n}{d^{n}Q(S)/ds^n}$$

for networks consisting of (*a*) reactances only, and (*b*) resistances together with reactances of one kind.

621.392.43 3533
Modified Exponential Line as Improved Transforming Element with High-Pass Characteristic—H. H. Meinke. (*Arch. elekt. Übertragung*, vol. 7, pp. 347–354; July, 1953.) For a given length of exponential line there is a critical frequency above which the transformation property becomes effective; at frequencies only a little above critical the transformation is only approximate. This drawback can be avoided by designing the line so that the characteristic impedance does not very exactly exponentially. Approximate line equations are derived for this case and practical forms of such lines are discussed; the influence of constructional defects is examined.

621.392.5 3534
A General Definition of Pass Band—S. Colombo. (*Compt. Rend. Acad. Sci.*, (Paris), vol. 237, pp. 427–429; Aug. 10, 1953.)

621.392.5 3535
RLC Lattice Networks—L. Weinberg. (Proc. I.R.E., vol. 41, pp. 1139–1144; Oct., 1953.) A method for synthesizing open-circuited lattice networks to have a required transfer impedance is based on the partial-fraction expansion of the given function. No mutual inductances are used, and series resistance is associated with all the self-inductances, so that low-Q coils may be used. A numerical example is worked out.

621.392.5 3536
Synthesis of Paralleled 3-Terminal RC Networks to provide Complex Zeros in the Transfer Function—P. F. Ordung, G. S. Axelby, H. L. Krauss, and W. P. Yetter. (*Trans. AIEE*, vol. 70, part II, pp. 1861–1867; 1951.) An improvement on the method given by Guillemin (2462 of 1949) is described which requires fewer paralleled networks. The desired transfer ratio is converted into the sum of several transfer ratios, each of which can be realized with a single ladder network. A method of synthesis for these networks in terms of a common driving-point-admittance function is described and theory developed for their connection in parallel. See also 656 of March (Ordung et al.).

621.392.5 3537
The Dual-Input Parallel-T Network—C. F. White and K. A. Morgan. (*Proc. NEC*, vol. 8, pp. 588–597; 1952.) The frequency of maximum attenuation in this type of circuit is a function of the ratio of the two input voltages. Various potentiometer-drive arrangements can be used for external tuning over a wide frequency range. Experimental results for a circuit with dual-potentiometer input are in good agreement with theory.

621.392.5 3538
Synthesis of the Transfer Function of 2-Terminal Pair Networks—R. Kahal. (*Trans. AIEE*, vol. 71, part I, pp. 129–134; 1952.) Full paper. See 1263 of May.

621.392.5:621.3.015.3 3539
The Possibility of defining the Width of the Pass Band in terms of the Distortion of a Transient—S. Colombo. (*Compt. Rend. Acad. Sci.*, (Paris), vol. 237, pp. 455–457; Aug. 18, 1953.) Analysis using the definition previously given (3534 above) indicates that it is impossible to define the distortion of a transient by a single build-up time.

621.392.5:621.318.435 3540
An Approximate Graphical Analysis of the Steady-State Response of Nonlinear Networks
S. Duninker. (*Philips Res. Rep.*, vol. 8, pp. 133–147; April, 1953.) An approximate graphical analysis is given for the case when one of the circuit parameters is varied gradually. Transients and the generation of subharmonics are not dealt with. The networks investigated consist of a nonlinear iron-cored inductor with ac and dc magnetization, in series with a linear resistor and linear capacitor. The results of the analysis can be applied to the investigation of the effects of resistive or reactive loads of magnetic amplifiers, and the utilization of jump phenomena (ferroresonance effects) in switching devices.

621.392.5.012.11:621.392.43 3541
A Theorem on the Impedance-Transforming Properties of Reactive Networks—L. Storch. (*Jour. Appl. Phys.*, vol. 24, pp. 833–838; July, 1953.) Two circle transformations, derived from the impedance-transformation properties of a 4-terminal network, are used to develop a "circle-locus" theorem which considerably simplifies analysis of impedance-matching networks. It is applicable to any linear reactive network with any arbitrary reference impedance not lying on the reactance axis.

621.392.5.015.3 3542
An Approximate Method of Obtaining the Transient Response from the Frequency Response—J. R. Wait. (*Canad. Jour. Tech.*, vol. 31, pp. 127–131; June, 1953.) The method is based on expressing the transient response $A(t)$ in terms of the real part of the frequency-response function, which is plotted on a logarithmic frequency scale and approximated by a series of straight-line segments. $A(t)$ is calculated from the slopes of these segments.

621.392.52 3543
Concerning the Minimum Number of Resonators and the Minimum Unloaded Q Needed in a Filter—M. Dishal. (*Trans. IRE*, PGVC-3, pp. 85–117; June, 1953.) The number of resonator elements required to meet given specifications of filter characteristics, and the lowest no-load values of Q which the resonators may have, can be deduced from the formulae and graphs given. The specifications include the "accept" and "reject" bandwidths, the peak/valley ripple ratio and response in the "reject" band of the selective circuit. Both constant-k and m-derived types of filter are considered, and numerical examples are worked out.

621.392.52.012.3 3544
Wave-Filter Characteristics by a Direct Method—R. C. Taylor and C. U. Watts. (*Trans. AIEE*, vol. 71, part I, pp. 96–100; 1952.) Full paper. See 961 of April.

621.392.52.029.3:621.396.645.371 3545
Audio-Frequency Filters using Negative Feedback—T. Janisz. (*Electronics*, vol. 26, pp. 222–228; Sept., 1953.) The operation is described of a two-tube amplifier with a series-resonance circuit across the cathode impedance of each of the two tubes, and a parallel-resonance circuit in the anode circuit of the first tube. A band-pass filter with a flat-topped response curve is obtained by adjusting the resonance frequency of the cathode circuit of the second tube to be intermediate to the cathode-circuit and anode-circuit resonance frequencies of the first tube.

621.392.6 3546
Nonlinear Multipoles—L. A. Zadeh. (*Proc. Nat. Acad. Sci.*, vol. 39, pp. 274–280; April, 1953.) A conceptual scheme is outlined which is intended to be used in conjunction with theories of oriented graphs and with machine computers for the analysis and design of non-

linear networks. A system of classes of nonlinear multipoles is defined, the classes being characterized by their responses to a particular set of pulses. See also 2598 of September.

621.396.6:061.4(443.611) 3547

The 17th National Radio-Components Exhibition—(*Onde élect.*, vol. 33, pp. 287–293; June, 1953.) Review of a selection of exhibits in the sections allotted to tubes, miscellaneous components and accessories, and measurement instruments at the exhibition held in Paris, February 27 to March 3, 1953.

621.396.6.002.2 3548

Printed Circuits and the Automatic Factory—R. A. Gerhold. (*Proc. NEC*, vol. 8, pp. 481–488; 1952.) Discussion of the application of the auto-sembly technique [353 of February (Danko)] to quantity production of a wide variety of electronic equipment, with substantial reduction of costs and economy in skilled personnel.

621.396.611.1 3549

Frequency Feedback—H. E. Hollmann. (*Proc. NEC*, vol. 8, pp. 577–587; 1952.) Discussion of a phenomenon which occurs in all resonant systems possessing a relation between resonance frequency and amplitude. In such systems there may be an external feedback channel, or internal feedback due to nonlinear reactors or to nonlinear resistors combined with fixed reactors, as in the so-called *RX* modulators. The phenomenon shows itself in asymmetrical deformation of the resonance curve. Applications of the effect in AM-FM conversion, and in FM-AM conversion for frequency-shift reception, are noted.

621.396.611.1:621.396.619.13 3550

A Method of Evaluation of the Quasi-Stationary Distortion of FM Signals in Tuned Interstages—J. J. Hupert. (*Proc. NEC*, vol. 8, pp. 445–461; 1952.) A graphical approach to the problem of designing low-distortion FM circuits, making use of the normalized derivative of the phase/frequency function, is shown to be preferable to that using the phase/frequency curve itself. The principles are applied to the determination of the distortion factor of a single tuned-circuits interstage and of a cascade arrangement of three stagger-tuned resonant circuits.

621.396.611.1.015.3 3551

Transient Phenomena in an Oscillatory Circuit with Variable Inductance—P. G. Gorodetski. (*Zh. Tekh. Fiz.*, vol. 22, pp. 1687–1692; Oct., 1952.) The operation of the circuit is discussed and a formula (2a) is derived for determining the variation of the current in the circuit. A numerical example is given.

621.396.611.21 3552

High-Frequency Crystal Units for use in Selective Networks, and their Proposed Application in Filters suitable for Mobile-Radio Channel Selection—D. F. Ciccolella and L. J. Labrie. (*Trans. IRE*, PGVC-3, pp. 118–128; June, 1953.) The design of bevelled AT-type quartz plates for use in band-pass crystal units is described. The reduction of unwanted modes of vibration, including thickness-shear overtone modes, is considered. Approximate electrical data for plated circular AT-type quartz plates with all unwanted modes reduced to a level 30 db below the response of the main thickness-shear mode are tabulated. The design is considered of a crystal filter with a mid-band frequency of 1.552 mc and bandwidths of 30 kc and 40 kc respectively at the 6-db and 100-db points.

621.396.611.21 3553

Thickness Vibrations of Piezoelectric Crystal Plates—R. Bechmann. (*Arch. elekt. Übertragung*, vol. 7, pp. 354–357; July, 1953.) Addendum to work noted in 357 of February.

621.396.611.31:621.318.42 3554

A Simple Method of Coupling Toroidal Coils—R. R. Darden, Jr. (*Proc. NEC*, vol. 8, pp. 618–620; 1952.) Theory is given of a method of coupling suitable for the low values of coupling coefficient usually required for IF transformers, FM discriminators and in some types of filter. The coupling coils, with very few turns, are wound on a separate toroidal core, each being connected in series with one of the toroidal coils to be coupled. In a simplified version a coupling coil of one or two turns, connected in series with one toroidal coil, is wound on top of the other toroidal coil. Such a transformer may be accommodated in a $\frac{3}{4}$-inch cube with the two toroids close together with no shield between them.

621.396.611.4:621.315.212 3555

Electromagnetic Waves in Hollow Metal Cylinders with Circular Cross-Section—R. Müller. (*Arch. elekt. Übertragung*, vol. 7, pp. 341–346; July, 1953.) The object of the paper is to co-ordinate the treatment of the subject and to clarify some points. The electric and magnetic lines of force are mapped in perspective. Other diagrams show the distribution of Poynting vector over the cross section and the currents in the walls. Wave propagation in concentric lines is investigated.

621.396.615:517.93 3556

Nonlinear Electromechanical Systems—G. Cahen. (*Rev. gén. élect.*, vol. 62, pp. 277–293; June, 1953.) By an extension of Liénard's graphical method (1928 Abstracts, p. 469) only two or three co-planar curves need be traced for a complete topological study of the stability conditions for systems represented by equations of the types

$$\ddot{x}+\dot{x}^2a(x)+\dot{x}b(x)+c(x)=0,$$

$$\ddot{x}+f(\dot{x})+\dot{x}b(x)+r(\dot{x})=0.$$

Results of a detailed analysis are applied to the case of a filtered oscillator (1279 of May and 1624 of June). A much shorter version of the first part of this paper was given in *Compt. Rend. Acad. Sci.*, (Paris), vol. 235, pp. 1003–1005; Nov. 3, 1952.

621.396.615.17 3557

A Study of the Triggering of a Plate-Coupled Multivibrator by Negative Pulses—S. K. Sen and B. M. Bhattacharyya. (*Indian Jour. Phys.*, vol. 26, pp. 597–616; Dec., 1952.) Experimental observations showed (*a*) that voltage waveforms at different electrodes were markedly influenced by the form of the input pulses, (*b*) that triggering action depended largely on the input-pulse amplitude, (*c*) that triggering might not take place for either very small or very large pulse amplitudes, depending on circuit arrangement, but larger amplitudes caused greater difficulties. Analysis of the circuit response to pulses of various durations and amplitudes gave results supporting the observations.

621.396.615.17 3558

Design of Triode Flip-Flops for Long-Term Stability—J. O. Paivinen and I. L. Auerbach. (*Trans. IRE*, vol. EC-2, pp. 14–26; June, 1953.) Description of an analytical method of design based on considerations of dc stability, limiting tolerances in respect of voltage and component values being taken into account initially. An Eccles-Jordan circuit with injection diodes is considered as a general case and equations are derived expressing the operating conditions in the grid and the anode circuits. Solution of these equations gives appropriate key values. The method is applied to three special cases and a numerical example is given.

621.396.615.17:621.396.619.13:621.317.083.7 3559

Wide-Band Data Transmitter—D. J. Gray, V. P. Gurske and W. E. Morrow. (*Electronics*, vol. 26, pp. 168–170; Sept., 1953.) A FM oscillator uses a double-phantastron circuit [2478 of 1948 (Close and Lebenbaum)] for a linear data-recording system. Signals in the range 0–5 kc can be handled with an accuracy to within 1 per cent. Full circuit details are given.

621.396.615.18 3560

Stable Frequency Dividers using Thyrite Elements—W. L. Hughes. (*Proc. NEC*, vol. 8, pp. 730–733; 1952.) Locked-oscillator frequency dividers using nonlinear thyrite elements as load impedors are described. With slight circuit modifications, a stable locking action is obtainable for division by any number between 1 and 10. No circuit adjustments are required as the valves age. Dividers have been constructed for frequencies up to 1 mc.

621.396.616:534.112.001.8 3561

Vibrating-Wire High-Q Resonator—A. W. Dickson and W. P. Murden. (*Electronics*, vol. 26, pp. 164–167; Sept., 1953.) Resonator units are described in which a wire of high tensile strength is stretched between long pole-pieces maintaining a strong transverse magnetic field. Resonance occurs when the frequency of current sent through the wire coincides with the natural frequency of the system. Theory is given and the equivalent electrical circuit analysed. With a tungsten wire mounted in vacuo, a Q value of 1840 has been obtained at 2.21 kc. Applications of such devices in filters and for frequency control are noted.

621.396.619.11/.13 3562

Spurious Frequency Modulation in Signal Generators—T. P. Flanagan. (*Marconi Instr.*, vol. 4, pp. 24–28; June, 1953.) The chief cause of FM in an AM circuit is the variation of tube input capacitance with modulation. Methods of reducing this effect are examined. Two circuits effective in reducing FM at vhf are described: (*a*) an untuned class-A amplifier with grid modulation; (*b*) a voltage-dividing network containing a crystal diode suitably biased to act as resistance.

621.396.645 3563

Valve Matching using Resistors—H. V. Harley. (*Wireless World*, vol. 59, pp. 488–493; Oct., 1953.) Desired characteristics can be obtained by including resistors in series and/or parallel with a tube; formulas for the effective parameters are tabulated for several simple combinations. Matching of ac characteristics may in practice be accompanied by reasonable matching of the over-all dc characteristics; a circuit is shown using the latter effect for determining resistances required for matching two tubes.

621.396.645:621.385.3.029.6 3564

A General Circle Diagram for the Input Admittance of a Grounded-Grid Disk-Seal Triode—E. Willwacher. (*Fernmeldetech. Z.*, vol. 6, pp. 328–331; July, 1953.) The method given takes account of the transconductance and anode-cathode capacitance of the triode. The effect of the transconductance phase, which depends on the electron transit time, is shown in the diagram. A numerical example is given. See also 3245 of November.

621.396.645.012 3565

Cathode-Follower Design Charts—N. O. Sokal. (*Electronics*, vol. 26, pp. 192–194, 196; Sept., 1953.) Output-impedance/input-voltage charts are shown for 9 commonly used tube types. Design procedure is outlined.

621.396.645.015.75 3566

On the Faithful Reproduction of the Flat Top of a Pulse in a High-Fidelity Pulse Amplifier—B. K. Bhattacharyya. (*Indian Jour. Phys.*, vol. 27, pp. 39–54; Jan., 1953.) The pulse amplifier analysed comprises a pentode with *rc* coupling circuits. Two methods of determining anode current, and hence amplifier

response, are applied, the one based on the overall-amplification reduction due to voltages across the parallel *rc* screen circuit and the *rc* cathode circuit, the other based on the superposition principle. Correction of pulse-top distortion is achieved by the anode-supply *rc* decoupling circuit; the conditions for satisfactory correction are derived.

621.396.645.029.3 3567
A Modern Broadcasting Pre-amplifier—Abadie and Blondé. (*Onde élect.*, vol. 33, pp. 468–472; July, 1953.) Description of a simple 2-stage feedback amplifier using Type-EF40 low-noise pentodes and suitable for use with sound reproduction equipment. Distortion is low, gain (40 db) practically uniform from 30 cps to 15 kc, and pickup of stray fields effectively negligible.

621.396.645.371.081.75 3568
Harmonic Distoriton and Negative Feedback—R. O. Rowlands. (*Wireless Eng.*, vol. 30, pp. 261–262; Oct., 1953.) Author's reply to comment by Kerr (3253 of November).

621.396.662.2:538.221 3569
Use of Ferromagnetic Materials in Electronic Tuning of Radiofrequency Components—S. Stiber. (*Proc. NEC*, vol. 8, pp. 462–468; 1952.) The change of the incremental permeability of a core of ferrite material due to a secondary superimposed magnetic field is discussed. The effect is utilized in the design of toroidal inductors whose inductance can be varied by altering the current in an auxiliary winding. Inductors of this type are incorporated in a receiver tunable from 500 kc to 3 mc, with a bandwidth of 11 kc at 500 kc and of 22 kc at 3 mc. The power required in the auxiliary tuning coil is <2 w. A variable inductor has been developed whose volume is <1 in.^{3}, weight slightly >1 ounce, and tuning range, for 2 w applied power, 7:1 in the frequency band 500 kc=3 mc, falling to 2:1 in the band 25–50 mc. See also *Electronics*, vol. 26, no. 7, pp. 186–188; July, 1953.

GENERAL PHYSICS

530.145:531.51:538.1 3570
The Relation of the Quantum Theory to the Theories of Gravitation and Electromagnetism, and an Application to the Theory of the Electron—H. T. Flint and E. M. Williamson. (*Z. Phys.*, vol. 135, pp. 260–269; June 25, 1953.)

534.01 3571
On an Iterative Method for Nonlinear Vibrations—R. E. Roberson. (*Jour. Appl. Mech.*, vol. 20, pp. 237–240; June, 1953.) Analysis of a method giving results analogous to those obtained by Duffing's method.

535.22+621.317.029.6]:061.3 3572
High-Frequency Electrical Measurements. Conference in Washington, D.C.—Essen. (*See* 3651.)

537.212 3573
A New Property of 2-Dimensional Fields—A. D. Moore. (*Trans. AIEE*, vol. 71, part I, pp. 343–346; 1952. Discussion, pp. 346–347.) Mapping of the field inside a nearly enclosed area is facilitated by working on the correlative field, whose derivation is explained. An analytical proof of the correlative property, based on the Schwartz-Christoffel transformation, is given in an appendix. The proof is due to W. R. Smythe. For a digest see *Elect. Eng.*, vol. 72, p. 290; April, 1953.

537.213+538.123]:517.947.42 3574
The Derivation of Vector Potential from Tables for Scalar Potential—J. J. Smith. (*Trans. AIEE*, vol. 71, part I, pp. 169–174; 1952.) Full paper. See 2285 of August.

537.228:535.37 3575
Field Strength and Temperature Studies of Electroluminescent Powders in Dielectric Media—S. Roberts. (*Jour. Opt. Soc. Amer.*, vol. 42, pp. 850–854; Nov., 1952.) Measurements were made on electroluminescent cells using Zn Se:Cu phosphor dispersed in a thermoplastic matrix. The intensity of luminescence depends critically on the field in the phosphor, and hence on its dielectric constant, but does not depend on the dielectric properties of the matrix except in so far as the latter provides a means of supporting a strong field in the phosphor. Little change of luminescent intensity was observed when the temperature was varied from -100 degrees to $+50$ degrees C, polystyrene being used as matrix.

537.228:535.37 3576
Dielectric Changes of Electroluminescent Phosphor during Illumination—S. Roberts. (*Jour. Opt. Soc., Amer.*, vol. 43, pp. 590–592; July, 1953.) Measurements were made of the dielectric properties of electroluminescent films composed as described previously (3575 above), for different values of applied voltage at 100 cps and for various wavelengths and intensities of illumination. The dielectric constant depends markedly on the illumination, the magnitude of the variations depending critically on the applied voltage. The effect exhibits a maximum at about 4046 Å.

537.311.31:539.23 3577
Development of the Electrical Resistance of Thin Films of Platinum subjected to a Relatively High Direct Voltage—M. Erny. (*Compt. Rend. Acad. Sci.* (Paris), vol. 237, pp. 387–389; Aug. 3, 1953.) Measurements made on films of different thicknesses, before and after the application of voltages of 300, 400 or 500 v, indicate that the resistance is increased, decreased or unchanged depending on the amount of heat developed, which in turn depends on the initial resistance and hence on the thickness.

537.311.32 3578
On Pre-Exponential Factors in Formulae for Ionic Conductivity in Solids—Y. Haven and J. H. van Santen. (*Philips Res. Rep.*, vol. 7, pp. 474–477; Dec., 1952.) If, in formulas for equilibrium constants and rate constants, energy is assumed to be proportional to temperature, the factor preceding the exponential term is not increased by a factor $\exp(\alpha/k)$, α being a constant and k Boltzmann's constant, but by a factor involving entropy.

537.52:621.3.066.6 3579
Initiation of Discharges at Electrical Contacts—F. L. Jones. (Proc. I.R.E., part I, vol. 100, pp. 169–173; Aug., 1953.) The experimental investigation described deals with discharges between low-power contacts, with special attention to the cases of make and break at medium voltage. The discharges were found to be initiated by a cold-field emission of electrons governed by the nature of the surface tarnish layers. The influence of the gas atmosphere was examined. A theory of the mechanism is outlined.

537.533:538.691 3580
On the Nonoptical Theory of Focusing in Rotating Magnetic Fields—P. I. Tsukkerman. (*Zh. tekh. Fiz.*, vol. 22, pp. 1843–1847; Nov., 1952.) The difficulties arising in the application of optical methods to electron optics are pointed out. The general theory of the focusing action of static magnetic fields developed by Grinberg, which is based on nonoptical methods, is applied to the case of paraxial electron beams in rotating magnetic fields.

537.533.8 3581
Measurement of Secondary Electron Emission—H. Gobrecht and F. Speer. (*Z. Phys.*, vol. 135, pp. 331–348; June 25, 1953.) The sources of error in secondary electron emission determinations are discussed in detail. Retarding-voltage curves, obtained experimentally, are analysed and a method of calculating the proportion of reflected primary electrons in the secondary electron current is given for the case when the target and spherical collector are made of the same material. For a Cr/Ni alloy and a primary potential at 1 kV, this proportion is 22 per cent.

537.533.9:[538.56.029.65+535.212 3582
Experiments on Radiation by Fast Electron Beams—H. Motz, W. Thon, and R. N. Whitehurst. (*Jour. Appl. Phys.*, vol. 24, pp. 826–833; July, 1953.) The design of a magnet system for an undulator, in which the field direction alternates periodically along the electron path [2411 of 1951 (Motz)], is described. A 100-mev electron beam from a linear accelerator was passed through the system; light radiated by the beam was observed and its plane of polarization was determined. Using a small linear accelerator with good bunching action and beam energy 3 mev, radiation at wavelengths below 1.9 mm was observed; peak power output was >1 w. Millimetre waves were also generated in the accelerator tube.

537.582:518.4 3583
Graphs for a Rapid Calculation of the Work Function of Thermionic Emission—C. G. J. Jansen and R. Loosjes. (*Philips Res. Rep.*, vol. 8, pp. 81–90; April, 1953.) A set of graphs is given for the saturation current density ($10^{-10}-10^{2}$A/cm^2) as a function of absolute temperature (300–2400 degrees K), with the work function (0.6–8 v) as parameter. The use of the graphs is explained.

537.71.081.5 3584
Dimensional Analysis, Units and Rationalization—R. Vermeulen. (*Philips Res. Rep.*, vol. 7, pp. 432–441; Dec., 1952.) Careless manipulation of dimensional formulas can lead to fallacious results. The trouble is due to the use of the multiplication sign for two different kinds of products having very different physical meanings. Once these are clearly distinguished, and the physical meaning considered at every stage in the proceedings, the difficulties encountered, even with rationalized units, are overcome.

538.11 3585
Antiferromagnetism—H. Labhart. (*Z. angew. Math. Phys.*, vol. 4, pp. 1–24; Jan. 15, 1953.) A survey paper. The distinction between antiferromagnetism and ferrimagnetism is indicated; the former is found mainly in simple inorganic compounds, the latter in complex compounds. Problems discussed concern the interaction between adjacent dipoles, the different possible arrangements within the various lattices, the magnetic properties, and the phenomena of the transition from order to disorder. 88 references.

538.114 3586
A Theory of Ferromagnetism—L. Pauling. (*Proc. Nat. Acad. Sci.*, vol. 39, pp. 551–560; June, 1953.) A theory is formulated that, when applied to iron, making use only of spectroscopic data for the Fe atom, gives a value of 2.20 Bohr magnetons for the saturation magnetic moment per iron atom and a value of 1350 degrees K for the Curie temperature. These values are in reasonable agreement with the experimental values of 2.22 magnetons and 1043 degrees K.

538.24 3587
The Calculation of the Magnetizing Force—A. A. Halacsy. (*Trans. AIEE*, vol. 71, pp. 90–95; 1952.) Full details of the method described in 1662 of 1950.

538.56:535.421 3588
The Electromagnetic Properties of a Plane Grating—V. M. Lopukhin and V. S. Nikol'ski. (*Zh. tekh. Fiz.*, vol. 22, pp. 1599–1605; Oct.,

1952.) A plane grating is considered which consists of a number of parallel conducting planes between which electron streams pass, and its waveguide properties are discussed, taking into account the velocity scatter of the electrons. A general solution of the problem is given for an arbitrary type of scatter function. The velocity scatter narrows the range of average velocities of the streams for which amplification is possible and displaces it towards the higher velocity values; the maximum amplification is also reduced.

538.566:535.135 3589
Propagation of Electromagnetic Waves in a Transparent Periodically Stratified Space—C. Dufour and A. Herpin. (*Rev. d'Optique*, vol. 32, pp. 321–348; June, 1953.) Equations derived for the general case are applied to the special case of a pile of double layers of equal optical thickness.

538.566:535.42 3590
Transmission of Electromagnetic Waves through Pairs of Parallel-Wire Grids—W. E. Groves. (*Jour. Appl. Phys.*, vol. 24, pp. 845–854; July, 1953.) An analytical solution is obtained for the power transmission coefficient of a double-grid system. Transmission coefficients are plotted as functions of the intergrid spacing for different wire spacing and angles of tilt. The curves are compared with those obtained by measurement at λ 3.2 cm using wire of radius 0.0875 cm. Agreement is good until the wire spacing approaches λ. Reasons for this divergence are noted.

538.566:537.562 3591
Plasma Oscillations in Crossed Electric and Magnetic Fields—A. I. Akhiezer and R. V. Polovin. (*Zh. tekh. Fiz.*, vol. 22, pp. 1794–1802; Nov., 1952.) An idealized case is considered and the specific structure which retards the em waves is replaced by a medium with an effective dielectric constant greater than unity. It is also assumed that the constant charge and current of the electron beam are compensated by the charge and current of ions which do not participate in the HF oscillations. With these assumptions, conditions are determined under which the electron beam becomes unstable, the fluctuations of the velocity and density of the beam increasing indefinitely.

538.566.2 3592
Extension of Fermat's Principle to Group Propagation Time—P. Poincelot. (*Compt. Rend. Acad. Sci.*, (Paris), vol. 237, pp. 382–384; Aug. 3, 1953.) Continuation of work noted in 3420 of 1952. It is shown by analysis that the difference between the group propagation times for two real paths joining the same two points is zero.

538.569.4 3593
Amplification of Microwave Radiation by Substances not in Thermal Equilibrium—J. Weber. (*Trans. IRE*, pp. 1–4; June, 1953.) Methods are discussed for the production of a nonequilibrium energy distribution, and the amount of amplification which may possibly be obtained by this method is calculated.

GEOPHYSICAL AND EXTRA-TERRESTRIAL PHENOMENA

523.72:621.396.822:621.396.677.1 3594
New Techniques in Radio Astronomy—Kraus and Ksiazek. (*See* 3490.)

523.746 3595
Extrapolation of Sunspot/Climate Relationships—S. W. Visser. (*Jour. Met.*, vol. 10, pp. 232–233; June, 1953.) Consideration of the periodicity of sunspot-number variations is based on taking the maximum year as the middle one of three successive maximal years. The next maximum should occur in 1959 and should be a strong one.

538.56:550.37 3596
Nonradiative Natural Oscillations of a Conducting Sphere surrounded by a Layer of Air and an Ionospheric Sheath—W. O. Schumann. (*Z. Naturf.*, vol. 7a, pp. 149–154; Feb., 1952.) A theoretical investigation having special reference to em oscillations of the earth, and relevant to the study of atmospherics. The dependence of the oscillation frequencies on the air-layer thickness and on the plasma properties is analysed. The lowest natural frequency to be expected for earth oscillations is about 11 cps. Oscillations of low frequencies are reflected at the inner surface of the plasma, while higher-order oscillations may penetrate right through the plasma and radiate into space.

538.56:550.37 3597
Damping of the Natural Electromagnetic Oscillations of the System Earth-Air-Ionosphere—W. O. Schumann. (*Z. Naturf.*, vol. 7a, pp. 250–252; March/April, 1952.) Continuation of work noted in 3596 above. An approximate formula is derived for the damping of the lowest-frequency oscillations, from which the the effective height of the air layer and the effective conductivity of the ionosphere can be determined.

551.510.535 3598
Electron Density in the Upper Atmosphere and Interpretation of the h′ f Curves of Ionosphere Virtual Height—F. Mariani. (*Ann. Geofis.*, vol. 6, pp. 21–45; Jan., 1953.) For the case of vertical incidence and the geomagnetic latitude of Rome, an expression is developed for the group refractive index using Appleton's formula. Absorption is neglected. The optical path of em waves totally or partially reflected or transmitted through an ionosphere layer is determined as a function of frequency for various cases. The results are applied in conjunction with experimental *h′ f* curves to derive linear relations giving directly the thickness of the layer and its height above the ground. Cases of single and superposed layers are treated.

551.510.535:621.3.087.4 3599
Instrumentation for Measuring Changes in Phase of Ionospheric Echoes—R. E. Jones. (*Rev. Sci. Instr.*, vol. 24, pp. 433–436; June, 1953.) Changes in carrier phase of ionosphere pulse echoes are determined from a comparison of the transmitted signal, stored by a "memory" circuit, with the echo signal received. The phase variation is presented, in the instrument described on a cro and a continuous photographic record is obtained. The equipment used is similar in principle to that of Findlay (397 of 1952). Results of E-region observations at 150 kc have been published by Davids (516 of February).

551.510.535:621.3.087.5:621.396.11 3600
COZI Communication-Zone Indicator—L. C. Edwards. (*Electronics*, vol. 26, pp. 152–155; Aug., 1953.) A general description, with block diagram of timing and indicating circuits, is given of a low-power oblique-incidence ionosphere sounder designed to indicate skip distances and communication zones from 500 to 2000 miles. Operation is on any one of six pre-set frequencies in the range 5–32 mc, peak pulse power 600–900 w, pulse duration 0.5–2.5 ms and repetition frequency 20/second. The one-hop skip distance is obtained directly from the time lag of the backscatter from the ground after single reflection from the ionosphere. Typical oscillograms show the increase of skip distance as the carrier frequency is increased in steps from 7 to 30 mc, the complete series of 12 records, two at each frequency, being obtained in 8 minutes.

LOCATION AND AIDS TO NAVIGATION

621.39.001.11:[621.396.9+621.397.5 3601
The London Conference, September 1952: Part 2—Radar and Television—J. Loeb. (*Onde élect.*, vol. 33, pp. 478–481; July, 1953.) A review of some of the papers presented at the conference on "Applications of the theory of information," dealing with the detection of signals in the presence of noise, the use of autocorrelation (theory and practice), the compression of television signals, and facsimile. Part 1: 3702 below.

621.396.9:519.21 3602
On the Statistical Theory of Detection of a Randomly Modulated Carrier—W. M. Stone. (*Jour. Appl. Phys.*, vol. 24, pp. 935–939; July, 1953.) "A method is outlined for estimating the probability of detection for a pulsed radar, assuming a randomly modulated carrier. For a square-law detector, closed forms for the moments of the distribution of the enevelope are presented in terms of three different choices of the distribution of carrier amplitude, thus leading to an Edgeworth series representation of the desired probability. At least one choice of distribution of the carrier amplitude leads to closed forms for the moments for the case of a linear detector. Curves of probability of detection vs signal-to-noise power ratio are constructed and cross checked by a method of numerical integration."

MATERIALS AND SUBSIDIARY TECHNIQUES

531.788.7 3603
New Developments in the Production and Measurement of Ultra-high Vacuum—D. Alpert. (*Jour. Appl. Phys.*, vol. 24, pp. 860–876; July, 1953.) Limitations of conventional ionization gauges are discussed, in particular X-ray effects, differences of sensitivity for different gases, and the pumping action of the gauge itself. Techniques and apparatus are described by which pressures down to 10^{-10} mm Hg are achieved without chemical getters, special traps or refrigerants; these include a Bayard-Alpert gauge (2785 of 1950) with special electrode arrangement for minimizing X-ray effects, two designs of a manipulative vacuum valve for very low pressures, an absolute manometer, methods of leak detection, and a power supply system for intermittent operation of the gauge.

533.5:537.525.5 3604
Clean-Up of Helium Gas in an Arc Discharge—M. J. Reddan and G. F. Rouse. (*Trans. AIEE*, vol. 70, part II, pp. 1924–1929; 1951.)

535.215.1 3605
On the General Criterion [for a choice] between the "Barrier Layer" and "Concentration" Theories of Photoconductivity—S. M. Ryvkin. (*Zh. tekh. Fiz.*, vol. 22, pp. 1693–1695; Oct., 1952.) The criterion proposed by Gibson (3157 of 1951) is stated to be insufficient; the choice between the "barrier layer" and "concentration" mechanisms should be decided by special experiments for each particular material.

535.215.1:537.533.7 3606
An Electron-optical Method of investigating Electromagnetic Fields and its Application to Investigation of the Internal Photoelectric Effect—V. S. Vavilov. (*Zh. tekh. Fiz.*, vol. 22, pp. 1644–1657; Oct., 1952.) A method similar to that used in optics by Foucault and Toepler is proposed. With the aid of the apparatus described a quantitative investigation of the drift of photocurrent carriers in an electric field in a semiconductor is possible. Observations are made of the redistribution of the potential along the samples when photoconduction is produced in them.

535.37 3607
Intrinsic Efficiencies of Phosphors under Cathode-Ray Excitation—A. Bril and H. A.

Klasens. (*Philips Res. Rep.*, vol. 7, pp. 401–420; Dec., 1952.) Measurements were made of the efficiencies of some 30 phosphors and of the light outputs for thin phosphor layers on aluminized or plain screens. For sulphide mixtures the maximum light output on the glass side was only 25 per cent of the total light emitted. Maximum gain when aluminized screens are used is less than that predicted by theory, because of absorption in the Al layer.

535.37 3608
New Phosphors for Flying-Spot Cathode-Ray Tubes—A. Bril and H. A. Klasens. (*Philips Res. Rep.*, vol. 7, pp. 421–431; Dec., 1952.) The following phosphors are recommended:—(*a*) for monochrome television, Ce-activated phosphors, particularly $2CaO \cdot Al_2O_3 \cdot SiO_2$-Ce, when the glass used does not blacken under cr or soft X-ray bombardment, (*b*) for the red component in colour-television tubes, Bi-activated phosphors, and (*c*) for ultraviolet flying-spot microscopy, ZrP_2O_7 phosphor.

535.37:546.472.21 3609
Copper-Activated Zinc-Sulfide Phosphors with Yellow and Red Emission—H. C. Froelich. (*Jour. Electrochem. Soc.*, vol. 100, pp. 280–288; June, 1953.) Long-wave emission was obtained by firing in an atmosphere of H_2S and using high activator concentration. The 6700-Å and 5800-Å bands are discussed.

535.372 3610
Alkaline-Earth Orthophosphate Phosphors—K. H. Butler. (*Jour. Electrochem. Soc.*, vol. 100, pp. 250–255; May, 1953.) The method of preparation and the emission spectra of orthophosphates of Ca, Sr, Ba and their mixtures are described. The primary activator used was Sm. Variation of the Mn secondary-activator content in certain of the phosphors results in a variation of the deep red color emitted.

537.311.33 3611
The Transport of Added Current Carriers in a Homogeneous Semiconductor—W. van Roosbroeck. (*Phys. Rev.*, vol. 91, pp. 282–289; July 15, 1953.) Transport equations are derived which show the dependence of (*a*) diffusivity and local drift velocity on concentration, and (*b*) the decay-time function on recombination. Carrier depletion with electrical neutrality may occur. For known total current density, the transport problem is determined by the continuity equation alone. In the case of small added-carrier concentration, the continuity equation assumes a mathematically simpler form, and relations are derived for Ge, which give the drift-velocity ratio, diffusivity and group mobility in terms of resistivity and temperature.

537.311.33 3612
Preliminary Data on the Relations between Lattice Defects and Debye R. F. Absorption in Iron Oxides—For "R. Freymann" please read "R. Freymann, R. Rohmer and B. Hagene" in 2328 of August.

537.311.33 3613
Thermoelectric Measurements on Copper Oxide at High Temperatures—H. Müser and H. Schilling. (*Z. Naturf.*, vol. 7a, pp. 211–212; Feb., 1952.) A note on experiments made to determine what types of semiconductor mechanism are possible in copper oxide at high temperatures.

537.311.33:537.312.6 3614
Determination of the Resistance/Temperature Characteristics of Bulk Semiconductors—R. B. McQuistan. (*Proc. NEC*, vol. 8, pp. 525—534; 1952.) Description, with detailed circuit diagrams of equipment using pulses of rectified current for heating the test sample and, in the intervals between pulses, displaying on a cro the resistivity and temperature of the sample. Graphs thus obtained for Ge, Si and Te agree with those obtained by conventional methods. See also *Electronics*, vol. 26, pp. 150–155; June, 1953.

537.311.33:539.23:546.289 3615
Semiconducting Films—W. M. Becker and K. Lark-Horovitz. (*Proc. NEC*, vol. 8, pp. 506–509; 1952.) Thin films of Ge deposited on quartz plates by thermal dissociation of GeH_4 were *p*-type at room temperature. Halli constant and resistivity curves for the temperature range 77.5–900 degrees K have quite a different shape from those for bulk Ge and the carrier mobilities are lower than usually found for bulk Ge.

537.311.33:[546.28+546.289 3616
Diffusion of Lithium into Germanium and Silicon—C. S. Fuller and J. A. Ditzenberger. (*Phys. Rev.*, vol. 91, p. 193; July 1, 1953.) Results are given of measurements at temperatures between 450 degrees and 1000 degrees C., using the method previously described [2822 of 1952 (Fuller)].

537.311.33:546.289 3617
Experimental Confirmation of Relation between Pulse Drift Mobility and Charge-Carrier Drift Mobility in Germanium—M. B. Prince. (*Phys. Rev.*, vol. 91, pp. 271–272; July 15, 1953.) Experimental data on drift mobilities of minority carriers in Ge are brought into agreement with theoretical predictions by distinguishing between group velocity and particle velocity of a pulse of minority carriers. Corrected high-temperature measurements of electron drift mobility are consistent with the theoretical prediction $\mu = AT^{-3/2}$. The experimentally determined value of A is 2.0×10^7.

537.311.33:546.289:621.317.335.3.029.64 3618
Microwave Measurements on Germanium Semiconductors—F. A. D'Altroy and H. Y. Fan. (*Proc. NEC*, vol. 8, pp. 522–524; 1952.) Measurements at 3-cm wavelength for a pure Ge sample and for one doped with Sb gave conductivities of 0.0266 $\Omega^{-1}cm^{-1}$ and 0.063 $\Omega^{-1}cm^{-1}$ respectively, the corresponding dc values being 0.025 and 0.055. The dielectric constants were respectively 15.4 and 15.6.

537.311.33:546.86.48 3619
Impurity and Intrinsic Semiconduction of Intermetallic Compounds: Part 1—E. Justi and G. Lautz. (*Z. Naturf.*, vol. 7a, pp. 191–200; Feb., 1952.) Compounds of Cd and Sb are considered. Experimental and theoretical investigations show that in Cd Sb the Brillouin zones are filled, hence this material is an intrinsic semiconductor. By adding small amounts of other metals impurity semiconductors are produced; these are examined in respect of variation of resistance with composition at room temperature. Properties distinguishing the intermetallic-compound semiconductors from other types are indicated.

537.311.33:621.314.63 3620
Relaxation Processes in Rectifying Pairs of Semiconductors—A. V. Joffe and A. F. Joffe. (*Zh. tekh. Fiz.*, vol. 23, pp. 209–224; Feb., 1953.) In order to investigate the slow processes which occur in a rectifying pair of semiconductors as a result of a contact or applied potential difference, and which gradually alter the resistance of the layers, experiments were conducted with Cu_2O+TiO_2 pairs. These experiments are described in detail, with numerous graphs and tables. A theoretical interpretation of the results is given; the primary cause of the observed phenomena is concluded to be the movement of ions in the semi-conductors. Calculations of the resistance, based on this assumption, show good agreement with the experimental results.

538.221 3621
Magnetic Viscosity of Ni-Zn Ferrites—E. F. Kuritsyna. (*Compt Rend. Acad. Sci. U.R.S.S.*, vol. 84, pp. 45–46; May 1, 1952. In Russian.) Three samples, of permeability μ_0 600, 650 and 1600, respectively, were investigated at 80 and 293 degrees K and the last sample also at 195 degrees K. Two maxima of relaxation time were observed, at field strengths corresponding to the points of inflexion of the hysteresis curve.

538.221:534.372 3622
The Origin of Damping in High-Strength Ferromagnetic Alloys—A. W. Cochardt. (*Jour. Appl. Mech.*, vol. 20, pp. 196–200; June, 1953.) The damping of vibrations is shown to be related mainly to the effect of magnetostriction.

538.221:536.631 3623
The Specific-Heat Discontinuity in Antiferromagnets and Ferrites—L. N. Howard and J. S. Smart. (*Phys. Rev.*, vol. 91, pp. 17–19; July 1, 1953.)

538.221:538.652 3624
Dynamical Physical Parameters of the Magnetostrictive Excitation of Extensional and Torsional Vibrations in Ferrites—C. M. van der Burgt. (*Philips Res. Rep.*, vol. 8, pp. 91–132; April, 1953.) Following a survey of the four sets of magnetostriction equations for given adiabatic conditions and arbitrary depolarization, the complex nature of the dynamic and magnetoelastic constants is discussed. The stress-sensitivity constant and the magnetomechanical coupling coefficient of several NiZn (Ferroxcube IV) materials, determined experimentally, are of the same order as for metallic magnetostrictive materials, but mechanical Q factors up to 15,000 at 50 kc have been obtained. The variation of elastic and magnetic lag with frequency and biasing polarization is discussed and the experimental correlation between conductivity and elastic and magnetic losses is explained.

538.632:[669.245.25+669.127.5 3625
Hall Effects of the Cobalt Nickel Alloys and of Armco Iron—S. Foner and E. M. Pugh. (*Phys. Rev.*, vol. 91, pp. 20–27; July 1, 1953.)

539.25:537.311.3 3626
Conductivity of Thin Films in a Longitudinal Magnetic Field—E. Koenigsberg. (*Phys. Rev.*, vol. 91, pp. 8–9; July 1, 1953.) Chambers' expression for the conductivity of a thin metal sample in a longitudinal field (2762 of 1950) is evaluated for thin films for two sets of boundary conditions.

546.226.161-1:621.317.333.6 3627
The Electric Strength of Sulfur Hexafluoride at Radio Frequencies—J. W. Gibson and C. F. Miller. (*Jour. Electrochem. Soc.*, vol. 100, pp. 265–271; June, 1953.) Measurements were made at 60 cps and in the range 2–16 mc at pressures of 5–20 lb/in². At 20 lb/in² the electric strength is 390 v/mil and is constant in a uniform field at frequencies up to 16 mc. The effect of electrode material and of irradiation from a Hg-arc lamp were also investigated.

546.47-31; [535.343.2+537.311.3 3628
Optical and Electric Properties of ZnO Single Crystals with Excess of Zn—E. Scharowsky. (*Z. Phys.*, vol. 135, pp. 318–330; June 25, 1953.) The dependence of electrical conductivity and light absorption on the excess of Zn was investigated.

546.74:621.38 3629
Nickel in Electronics—K. Jackson and R. O. Jenkins. (*Metallurgia, Manchr*, vol. 47, pp. 277–282; June, 1953.) A survey is given of the properties of Ni and its alloys and of their applications in electronic tube manufacture. Gas liberation from Ni and the effects of im-

purities are discussed and the choice of material for various tube components is considered in detail.

621.314.63 3630

The Dynamical Theory of Solid Rectifiers: Part 1—Limits of Applicability of the Static Theory—A. I. Gubanov. (*Zh. tekh. Fiz.*, vol. 22, pp. 1803–1813; Nov., 1952.) From an analysis of nonstationary diffusion equations, limits are determined for the applicability of the static theory of solid rectifiers previously proposed (2745 of 1951 and 424 of 1952) for the case of a rectifier operating with an alternating voltage of the order of a few volts. Increase of the frequency affects first of all the establishment of an equilibrium between the numbers of mobile and fixed charges, and this effect becomes noticeable at the main frequency of 50 cps and above. The redistribution of mobile charges in the barrier layer of the rectifier is, however, independent of frequency up to about 1 mc.

621.314.63 3631

The Dynamical Theory of Solid Rectifiers: Part 2—Frequency Characteristic—*A. I.* Gubanov. (*Zh. tekh. Fiz.*, vol. 22, pp. 1814–1826; Nov., 1952.) The effect is considered of the frequency of an alternating voltage, of the order of a few volts, applied to a solid rectifier, on the distribution of fixed charges in the barrier layer. The distribution of potential is calculated as well as conduction and displacement currents as determined by the frequency. The lowering of the rectification factor in the case of an alternating current is due to the resulting displacement current, which increases with frequency. A numerical example is given for the case of a Cu_2O rectifier, and curves are plotted showing the frequency dependence of the backward and displacement currents of the rectifier, and the variation of these currents with time during the negative half-cycle.

621.315.5.015.5 3632

Recent Information on Electric Breakdown—K. Konstantinowsky. (*Elektrotech. u. Maschienb.*, vol. 70, pp. 224–230; May 15, 1953.) Results recently published on various aspects of breakdown of insulating materials, cable insulation in particular, are reviewed.

621.315.61 3633

Electrical and Physical Properties of IN-420: a New Chlorinated Liquid Dielectric—A. J. Warner. (*Trans. AIEE*, vol. 71, part I, pp. 330–335; 1952; *Eleck. Commun.*, vol. 30, pp. 118–123; June, 1953.) Particularly suitable as an impregnant for capacitors to be used at temperatures up to 125 degrees C.

621.315.616.96 3634

New Electrical Insulating Materials—P. Jolivet. (*Rev. gén. Eléct.*, vol. 62, pp. 267–275; June, 1953.) The chemical structure, preparation, properties and applications of nine organic solids are detailed: five vinyl resins, aniline formaldehyde, and ethoxylene, alkyd and silicone resins.

621.318+621.315.612+548.55 3635

Modern Trends in Communication Materials—L. A. Thomas. (*Jour. Brit. IRE*, vol. 13, pp. 356–360; July, 1953.) Ferroelectric dielectrics, magnetic core materials and synthetic crystals are discussed; crystal valves are not dealt with.

621.318.134 3636

Losses in Ferroxcube Rods and Tubes—H. van Suchtelen. (*Electronic Applic. Bull.*, vol. 13, pp. 109–114; July, 1952.) Approximate formulas are derived for the loss angle for rods and tubes with windings over the whole or a short part of their length. The results indicate that, for high quality, tube cores and short coils on long rods should not be used. Measurements on ferroxcube IV B rods and tubes confirm the calculations.

666.19:621.392.5 3637

Vitreous Silica for Ultrasonic Delay-Line Applications—E. S. Pennell. (*Proc. NEC*, vol. 8, pp. 799–810; 1952.) The vitreous silica for ultrasonic delay lines must be free from strain or other source of birefringence and must be clear and homogeneous. Tests with polarized light of material from various sources are described. The material Ultrasil obtained from the Heraeus works, Hanau, Germany, was found to be of particularly good quality.

666.29:621.387.424.032.79 3638

Enamel Seal for Thin Mica Windows in Glass Tubes—R. Meunier and M. Bonpas. (*Le Vide*, vol. 8, pp. 1342–1343; May, 1953.) Description of a process developed for Geiger-Müller tubes.

MATHEMATICS

512.831:621.3 3639

On Matrix Algebra and the Application of 'Normalized Magnitudes' in Electrical Engineering—H. Frühauf. (*NachrTech.*, vol. 3, pp. 263–268; June, 1953.) The methods are illustrated by calculations of the band-pass characteristics of coupled tuned circuits.

517.9 3640

Matrix Solution of Equations of the Mathieu-Hill Type—L. A. Pipes. (*Jour. Appl. Phys.*, vol. 24, pp. 902–910; July, 1953.) The equations discussed are encountered in radio circuit and propagation theory.

518.5:621.3.018.75 3641

A Graphical Spectrum Analyzer for Pulse Series—H. P. Raabe. (Proc I.R.E., vol. 41, pp. 1129–1138; Oct., 1953.) Description of theory and operation of a mechanical device similar to a slide rule, for presenting graphically the frequency spectrum of an infinite series of pulses having amplitude modulation but no frequency modulation.

681.142 3642

The Approximation of Arc-Tangent ω with a Linear Electrical Network—D. L. Finn. (*Proc. NEC*, vol. 8, pp. 435–444; 1952.)

681.142 3643

A Stabilized Electronic Multiplier—C. D Morrill and R. V. Baum. (*Proc. NEC*, vol. 8, pp. 710–715; 1952.) Description of a time-division multiplier for obtaining the product of two or more variable voltages to within 0.1 per cent.

681.142 3644

Computing Machines—R. Bird. (*Electronic Eng.*, vol. 25, pp. 407–410; Oct., 1953.) Computers for business calculations are considered and methods are described for converting information on punched cards into the binary system, and vice versa.

681.142 3645

Serial Digital Adders for a Variable Radix of Notation—R. Townsend. (*Electronic Eng.*, vol. 25, pp. 410–416; Oct., 1953.) Methods are described by means of which business data, such as £.s.d. figures, can be handled in a binary-system computer.

681.142 3646

A Magnetic-Drum Digital-Storage System—B. F. C. Cooper. (Proc. I.R.E., vol. 14, pp. 169–177; Sept./Oct., 1953.) This magnetic-drum system was designed as auxiliary store for the C.S.I.R.O. Mark I computer previously described [1050 of April (Beard and Pearcey)]. It has a capacity of 1024 "words" of 20 binary digits and its rotation rate of 6000 rpm gives an average access time of 5 ms for random references. Associated basic circuits are described.

681.142 3647

Hidden Regenerative Loops in Electronic Analog Computers—L. G. Walters. (*Trans. IRE Engrs.*, vol. EC-2, pp. 1–4; June, 1953.) Detailed analysis showing how coupling due to energy-storing elements gives rise to regenerative loops, the gain of which determines the system stability.

681.142:016 3648

Storage Systems in Arithmetical Computers—R. Dussine. (*Onde élect.*, vol. 33, pp. 453–455; July, 1953.) Annotated references are given to 21 papers dealing with systems based on pulse counting, or on the use of (*a*) ultrasonic or electrical delay lines, (*b*) cr tubes, (*c*) magnetic materials.

681.142:621.385.832.082.72 3649

The Scotch-Plaid Raster—J. Kates and V. G. Smith. (*Trans. AIEE*, vol. 70, part II, pp. 1480–1484; 1951.) Substantial advantages for digit storage on a cr tube screen are derived from use of a raster with nonuniform spacing, the raster resembling the stripes of a Scotch plaid. Theory is given for two types, the "minimum tolerance" and the "uniform probability" raster.

681.142:621.392.5 3650

Electrical Delay Lines for Digital Computer Applications—J. R. Anderson. (*Trans. IRE*, vol. EC-2, pp. 5–13; June, 1952.) The maximum storage capacity of commercially available lumped-parameter and distributed-parameter delay lines is about 23 and 15 pulses respectively, regardless of total delay time. An analysis indicates that dissipation in inductive elements is the chief limiting factor. Insertion loss can be reduced and storage capacity increased to about 32 pulses by using as inductive elements low-permeability, high-*Q*, Ni-Zn ferrites around straight single conductors. The design of such units is described.

MEASUREMENTS AND TEST GEAR

621.317.029.6+535.22]:061.3 3651

High-Frequency Electrical Measurements. Conference in Washington, D. C.—L. Essen. (*Nature*, vol. 172, pp. 52–54; July 11, 1953.) A brief account of some of the papers read at the third biennial conference organized by the A.I.E.E., I.R.E. and N.B.S. and held during January 14–16, 1953.

621.317.3:535.326:621.396.677 3652

Microwave Measurements on Metallic Delay Media—S. B. Cohn. (Proc. I.R.E., vol. 41, pp. 1177–1183; Oct., 1953.) Determinations have been made of the refractive index of microwave-lens delay media comprising alternate polyfoam spacers and thin polystyrene sheets printed with patterns of conducting areas. The measurement equipment and method are described and necessary correction formulas are given. Results are presented in the form of graphs useful for design purposes.

621.317.321 3653

Voltmeter Loading Again—R. A. Wiersma. (*Wireless World*, vol. 59, pp. 499–500; Oct., 1953.) A simple method is given for determining the true voltage in a high-resistance circuit when using a single universal meter.

621.317.333.6:546.226.161-1 3654

The Electric Strength of Sulfur Hexafluoride at Radio Frequencies—Gibson and Miller. (*See* 3627.)

621.317.335.029.65 3655

Dielectric Constant Measurements at 8.6-mm Wavelength—P. Hertel, Jr., A. W. Straiton and C. W. Tolbert. (*Jour. Appl. Phys.*, vol. 24, pp. 956–957; July, 1953.) Values of permittivity and conductivity were determined from measurements of the attenuation and phase shift of 8.6-mm waves passed through the dielectric. Values obtained for water, ethyl

alcohol and soil are compared with the results of other workers.

621.317.335.3+621.317.374].029.6 3656
Measurements of the Loss Angle and Permittivity of Solid Dielectrics in the Region of Ultra-Short and Decimetric Waves—K. A. Vodop'yanov and B. I. Vorozhtsov. (*Zh. tekh. Fiz.*, vol. 22, pp. 1877–1880; Nov., 1952.) Various methods developed by Soviet physicists are reviewed and optimum conditions for their application are indicated.

621.317.336:621.385.029.64/.65:513.647.1 3657
Helix Impedance Measurements using an Electron Beam—Watkins and Siegman. (*See* 3753.)

621.317.336.1:621.314.222 3658
A Meter for Measuring the Coefficient of Coupling of I. F. Transformers—E. A. Saunders and G. R. Cooper. (*Proc. NEC*, vol. 8, pp. 609–617; 1952.) A method is described for measuring the coupling coefficient k in terms of the change in the antiresonance frequency of the primary coil and tuning capacitor with the secondary short-circuited and then on open circuit. A variable-frequency oscillator of the type described by Crosby (2156 of 1946), including the primary circuit, is set to zero beat with a fixed-frequency oscillator, the transformer secondary being short-circuited. Measurements of the beat frequency obtained when the transformer secondary is on open circuit are made by means of a single-shot multivibrator giving a series of pulses, of constant amplitude and duration, which are fed to a dc microammeter calibrated to read k directly from 0.01 to 0.4, the accuracy being to within 3 per cent. The frequency range covered is from about 300 kc to 1 mc secondary resonance frequency.

621.317.342:621.392.5 3659
Measurement of Group-Delay Time in Networks—A. van Weel. (*Philips Res. Rep.*, vol. 7, pp. 467–473; Dec., 1952.) Measurement of the phase variation impressed on a LF modulation of a HF carrier during passage through an unknown network is made by introducing the phase variation into a LF oscillatory circuit and measuring the resultant frequency variation. Under stated conditions there is a linear relation between the group-delay variation and the frequency variation. The choice of amplifier delay time (t) and frequency (f) depends on the sensitivity required and the maximum group-delay variation to be measured. For the instrument described $t=\sim70$ μs, $f=$ 30 kc, and the sensitivity ~0.01 degree; group-delay variations between 10^{-9} and 10^{-6} seconds can be measured.

621.317.361:621.396.619.13 3660
Direct Measurement of Frequency of Modulated F.M. Transmitters by Pulse Counting—H. M. Schmidt. (*Frequenz*, vol. 7, pp. 203–209; July, 1953.) Two instruments are described capable of indicating the mean frequency of a FM signal (with a frequency deviation of ±75 kc) with an absolute accuracy within ±50 cs. The received signal is heterodyned to a lower frequency, and the count is made in the one case by means of a continuously integrating device, and in the other by means of a circuit which averages the count over an adjustable period.

621.317.382.029.6 3661
Mismatch Errors in Microwave Power Measurements—R. W. Beatty and A. C. Macpherson. (PROC. I.R.E., vol. 41, pp. 1112–1119; Oct., 1953.) Expressions are derived for error due to mismatch when an UHF or microwave power meter is calibrated by comparison with a standard power meter, e.g. a bolometer device. The comparison may be made by (a) alternate connection to a stable power source, (b) simultaneous connection to a T or magic-T junction, or (c) alternate connection to a T or magic-T junction. Expressions are also derived for the mismatch error when using a calibrated power meter in the cases where (a) the power meter is directly connected to the source, (b) an attenuator is interposed, and (c) a directional coupler is interposed.

621.317.7:621.314.63 3662
Harmonic-Insensitive Rectifiers for A.C. Measurements—R. L. Frank. (*Proc. NEC*, vol. 8, pp. 495–505; 1952.) Measurements with a rectifier-type instrument of the amplitude of the fundamental of an alternating current may be in error if harmonics are present. The average type of rectifier circuit, with conduction over 180 degrees, is insensitive to even harmonics and the error due to odd harmonics decreases as the order of the harmonic increases. By using a rectifier circuit giving conduction over 120 degrees of phase angle, insensitivity to third harmonics is achieved. The performance of 120 degree-conduction and 180 degree-conduction circuits for various harmonic levels is analysed. For nonsinusoidal wave forms the 120 degree-conduction circuit gives a close approximation to the true rms value. Applications in a general-purpose ac voltmeter and a precision triple-balanced phase comparator are described.

621.317.7:621.392.43 3663
Balance Measurements on Balun Transformers—O. M. Woodward, Jr. (*Electronics*, vol. 26, pp. 188–191; Sept., 1953.) Balun transformers can be rated in terms of the percentage ratio of the balanced-mode components of load current to total load current. The balance comparator is designed to provide the measurement equipment required. It comprises a generator, the balun under test and a variable load. The load consists of two short slotted coaxial lines, with carbon-resistor inner conductors, arranged at right angles to each other. The indicator has a single-turn loop which is rotated to the positions at which its indication is proportional only to either the unbalanced or the balanced load-current components. Short symmetrical connection between the balun under test and the comparator terminals is essential. Results of measurements on baluns for about 60 and 700 mc are discussed.

621.317.7:621.396.619.13 3664
The Design of Measuring Equipment for the Determination of Circuit Performance of F.M. Systems—A. G. Wray. (*Jour. Brit. IRE*, vol. 13, pp. 363–375; July, 1953.) The measuring equipment is considered under the following headings:—(a) generators, which may be either of the beat-frequency or the harmonic type; (b) detection equipment, in particular deviation meters including low-distortion high-stability discriminators, the pulse-counter type being recommended; (c) FM station monitor; (d) spectrum analysers with cro display and sweep-frequency oscillator, the sweep produced either electronically or mechanically.

621.317.7.083.4 3665
The Requirements and Design for a D.C. Null Detector.—F. L. Maltby. (*Trans. AIEE*, vol. 70, part II, pp. 1876–1881; 1951. Discussion, pp. 1881–1883.) Equipment is described in which a synchronous reversing switch is used to convert the error direct voltage into an alternating voltage at the mains frequency. This alternating voltage is amplified and applied to the control winding of a 2-phase balancing motor whose reference winding is energized continuously at the mains frequency. Design requirements are discussed and circuit details given.

621.317.715:621.314.58 3666
The Induction Galvanometer, a Sensitive Instrument Converter—R. W. Gilbert. (*Trans. AIEE*, vol. 70, part II, pp. 1121–1126; 1951. Discussion, p. 1126). Detailed description of the construction and operation of an instrument consisting essentially of a conventional permanent-magnet moving-coil galvanometer with the addition of means for injecting an ac component of magnetic flux into the permanent-magnet field. Deflection of the coil due to dc produces a proportionate alternating voltage in the coil, which is amplified by a special frequency-shift amplifier. A commercial design for 200-kc conversion is illustrated, for which the conversion gain, defined as the ratio of energy developed in the moving-coil impedance (~300Ω) to the dc energy producing it, may be as high as 4×10^{10}. When properly adjusted, the galvanometer deflection for full output deflection is estimated as about 5 seconds of angle.

621.317.755.015.7 3667
Pulse Oscillograph—W. Eckardt. (*Nachr-Tech.*, vol. 3, pp. 250–257; June, 1953.) Description of equipment for pulse widths of 1–300 μs and pulse repetition frequencies up to 10^5/seconds.

621.317.761.029.64/.65 3668
Accurate Frequency Meters for the Range 22–37 kMc/s.—Bonnet. (*Onde élect.*, vol. 33, pp. 259–269; June, 1953.) A description is given of the construction and method of use of two meters of the cavity-resonator type, differing only in the diameters of the cavities and the spacing of the holes for coupling to a waveguide. Preliminary calibration was effected by means of the NH_3 absorption lines. Accurate measurements make use of harmonics of a 15.275-mc quartz crystal, a cro method being adopted for identification of the harmonics and of the oscillation modes used, which are mainly H_{011}, H_{012} and H_{013}. Measurement accuracy is of the same order as that to which the quartz-crystal frequency is known.

621.317.783/.784:621.316.313 3669
An Electronic Wattmeter—W. B. Boast. (*Proc. NEC*, vol. 8, pp. 716–724; 1952.) Description of the method of operating conventional electrodynamometers at 10 kc from specially designed amplifiers, for making accurate measurements of power and reactive power on the ac-network analyser at Iowa State College.

621.317.79:621.396.611.21 3670
A Review of Methods for Measuring the Constants of Piezoelectric Vibrators—E. A. Gerber. (PROC. I.R.E., vol. 41, pp. 1103–1112; Sept., 1953.) The equivalent-circuit representation of piezoelectric vibrators is shown, and the fundamental parameters indicated. Measurement methods are considered under two headings, viz., routine and laboratory. For routine measurements, methods are preferred in which the crystal under test constitutes the frequency-controlling element in the circuit of the test oscillator. To obtain the greater precision required with laboratory measurements, bridge circuits are preferred.

621.396.615.029.63/.64 3671
An S-Band Sweep Generator and Test Set—J. H. Kluck and R. E. Larson. (*Proc. NEC*, vol. 8, pp. 823–830; 1952.) The generator provides a single sweep from 2.6 to 3.6 km or a 100-mc sweep whose center frequency can be anywhere within the range 2.6–3.8 kmc. The frequency sweep is obtained by mixing the outputs of two K-band klystrons. Square-wave modulation equipment, and a detector system consisting of a wide-band bolometer, tuned amplifier and cro, are provided to give a visual indication of the frequency response of S-band components. Typical oscillograms obtained with the equipment are reproduced.

621.396.615.17.015.7 3672
A Wide-Range Pulse Generator for Laboratory Applications—R. W. Frank. (*Proc.*

NEC, vol. 8, pp. 811–822; 1952.) Description, with schematic circuit diagrams, of a pulse generator, developed by the General Radio Co., providing pulses of duration from 0.05 μs to 0.1 second, with rise and fall times of 0.025 μs. The pulses are derived from a linear sawtooth wave which is also available. A delay system for phasing applications can be calibrated over the range 1 μs—0.15 second. The sweep circuit gives an amplitude sufficient for full deflection of the beam of a standard 5-in. cr tube. Any output impedance up to 600Ω can be chosen.

OTHER APPLICATIONS OF RADIO AND ELECTRONICS

532.137:621-526 3673
Design and Construction of a Viscometer with Electronic Servomechanism—P. Jung. (*HF, Brussels*, vol. 2, pp. 189–196; 1953.) Operation of the Couette viscometer is improved by incorporating a servomechanism.

621.317.083.7 3674
A High-Speed Telemetering System with Automatic Calibration—W. E. Phillips. (*Trans. AIEE*, vol. 70, part II, pp. 1256–1260; 1951. Discussion, pp. 1260–1261.) Description of equipment using frequency bands of 20–25 cps and 80–100 cps for signal transmission. At the receiving end a converter produces a direct voltage, proportional to the frequency of the incoming signal, which operates a recorder.

621.317.083.7:551.508.11 3675
A Radar Sonde Installation—(*Electronic Eng.*, vol. 25, p. 416; Oct., 1953.) Brief description of fully automatic equipment for the British Meteorological office, consisting of ground interrogator and computing station working in conjunction with airborne transponders. For a somewhat fuller account see *Elec. Jour.*, vol. 151, pp. 651–652; Aug. 28, 1953.

621.365.54:†016 3676
Bibliography on the Present-Day Technology of H.F. Generators for Induction Heating—J. Reboux. (*Onde élect*, vol. 33, pp. 456–460; July, 1953.) A list, with notes, of 35 publications dealing with (*a*) the basic theory and practice of HF induction heating, (*b*) design of suitable generators, (*c*) practical applications.

621.384.612/.613 3677
Automatic Ejection in Betatrons and Synchrotrons—L. W. von Tersch and R. L. Doty. (*Proc. NEC*, vol. 8, pp. 703–709; 1952.)

621.384.612 3678
Origin of the (Strong-Focusing' Principle—E. D. Courant, M. S. Livingston, H. S. Snyder, and J. P. Blewett. (*Phys. Rev.*, vol. 91, pp. 202–203; July 1, 1953.) Note pointing out that N. Christophilos, in an unpublished manuscript prepared in 1950, proposed an accelerator on the same lines as that described in 1454 of May.

621.384.622.1 3679
A Portable 250-Kilovolt Accelerator—T. A. Bergstralh, K. L. Dunning, E. Durand, C. H. Ellison, H. K. Howerton, and W. Slavin. (*Rev. Sci. Instrum.*, vol. 24, pp. 417–419; June, 1953.)

621.385.833 3680
Angular Aberrations in Sector-Shaped Electromagnetic Lenses for Focusing Beams of Charged Particles—E. G. Johnson and A. O. Nier. (*Phys. Rev.*, vol. 91, pp. 10–17; July 1, 1953.)

621.385.833:061.3 3681
Electron Optics. Symposium in London—O. Klemperer. (*Nature*, vol. 172, pp. 61–62; July 11, 1953.) A brief report on the Physical Society symposium on "Recent Research in Electron Optics" held during May 15–16, 1953.

621.387.424 3682
A Battery-Operated Geiger-Muller Counter—G. Hepp. (*Philips Tech. Rev.*, vol. 14, pp. 369–376; June, 1953.)

621.389:621.396.645.35:541.132.3 3683
Electronic Instrumentation applied to the Chemical Industry, with special reference to pH Measurement—G. Hitchcox. (*Jour. Brit. IRE*, vol. 13, pp. 401–411; Aug., 1953.) The design of the direct-reading continuous-service pH meter is discussed; this is essentially a stable dc amplifier, either direct-coupled or with conversion to ac; two typical commercial instruments are described.

621.397.9 3684
Measurement of the Size-Distribution of Spray Particles—L. K. Wheeler and E. S. Trickett. (*Electronic Eng.*, vol. 25, pp. 402–406; Oct., 1953.) A phototelegraph transmitter is used to scan spot patterns produced by a spray, and the resulting pulses are passed to a discriminating device.

681.26:621.38:681.178 3685
Ultrarapid Electronic Balance—A. Jeudon. (*Ann. Télécommun.*, vol. 8, pp. 190–196; June, 1953.) Description of feedback equipment producing a current proportional to the applied force up to a maximum weight of 30 g, with application to detection of over-weight letters.

PROPAGATION OF WAVES

538.566 3686
The Nonexistence of Sommerfeld's Surface Wave—P. Poincelot. (*Ann. Télécommun.*, vol. 8, pp. 206–211; June, 1953.) See 195 of January.

538.566:537.311.3 3687
General Method of Determining the Conductivity of Heterogeneous Ground—M. Argirovic. (*Ann. Télécommun.*, vol. 8, pp. 212–224; June, 1953.) A critical propagation zone is reached when the value of Sommerfeld's 'numerical distance' is $> e$, the base of Napierian logarithms. Study of the critical point leads to two very simple expressions for the attenuation factor and to a curve differing slightly from that of Sommerfeld near the critical point. From the rule for the sum of numerical distances (distances $<e$), a method is developed for the direct determination of ground conductivities, and zones of equal conductivity, from measured values of field strength and range. A graphical method of evaluating the required quantities is described. The method has been applied to calculations of night-attenuation curves. Comparison of the calculated values of ground conductivity with measured values for particular transmission paths shows satisfactory agreement.

621.396.11 3688
Radio Propagation over a Flat Earth across a Boundary Separating Two Different Media—P. C. Clemmow. (*Phil. Tranz.*, vol. 246, pp. 1–55; June 15, 1953.) A theoretical investigation is made of the propagation of vertically polarized waves, assuming in the first place an earth model consisting of an infinitely thin perfectly conducting half-plane lying in the surface of an otherwise homogeneous earth. The resulting boundary-value problem is solved for a plane wave inclined at an arbitrary angle, and the solution for a line source is obtained in the form of an integral equation. The case when transmitter and receiver are both at ground level is considered in detail; when the distance between them is large the solution becomes simplified, giving results in agreement with those of Feinberg (1902 of 1947). The possibility of an increase of field strength just beyond the boundary is confirmed. A different approximation is obtained when the transmitter and receiver are elevated; this is used to indicate the validity of height-gain factors. For the usual practical case of two regions with arbitrary complex permittivity, approximate boundary conditions are introduced into the analysis. Attenuation and phase curves are given for a numerical example, the attenuation results being in good agreement with those reported by Millington (2307 of 1949).

621.396.11 3689
Predictions of Optimum Working Frequency in Washington and in Madrid—R. Gea Sacasa. (*Rev. Telecommun., Madrid*, vol. 9, pp. 2–20; June, 1953.) Predictions made by the "Spanish Method" (3536 of 1952) and based on data for Madrid are compared with predictions made by the C.R.P.L. for a number of circuits in the region of latitude 40 degrees N in North America and for two circuits linking the U.S.A. and Europe. The main points of agreement and disagreement are discussed. It is suggested that when correction is made for seasonal variation of critical frequencies, the sunspot cycle may be found to have no effect on ionospheric propagation.

621.396.11:551.510.535 3690
Studies on Ionospheric Absorption—B. Chatterjee. (*Indian Jour. Phys.*, vol. 26, pp. 585–596; Dec., 1952.) The factors causing ionospheric absorption are briefly reviewed and the method applied in the systematic observations instituted at Calcutta is described in some detail. Typical graphs showing the variation of absorption with frequency are discussed. There is a marked increase in absorption near the critical frequencies of the layers. When magneto-ionic splitting occurs, the extraordinary component usually suffers greater absorption. When an E_s layer is present, certain F echoes are more highly attenuated. Very high absorption on all sw frequencies on particular nights is explained as a result of the formation of a sporadic-D layer.

621.396.11:551.510.535 3691
The Calculation of the Path of a Radio-Ray in a Given Ionosphere—A. H. de Voogt. (Proc. I.R.E., vol. 41, pp. 1183–1186; Oct., 1953.) A general formula is derived giving the electron density in the ionosphere as a third-degree function of height. The form of the distribution curve can be brought into coincidence with previously proposed distribution curves by inserting appropriate values for the formula constants, in accordance with ionospheric soundings. Exact calculations can be made of transmission time, greatest height reached, and distance travelled on the earth's surface, for a given angle of departure of a ray. Details of the calculations are available on request from the PTT-Radio-Service, Scheveningseweg 6, The Hague.

621.396.11:551.510.535:621.3.087.5 3692
COZI Communication-Zone Indicator—Edwards. (*See* 3600.)

621.396.11:621.317.353.3† 3693
Solar Influence in Gyro-interaction Experiments—G. Righini and G. Godoli. (*Ann. Geofis.*, vol. 6, pp. 11–19; Jan., 1953.) Statistical analysis of data collected during the period 1948–1950 shows that it is exceedingly improbable that there is any solar influence on gyro-interaction.

621.396.11.029.63:551.5 3694
Ultra-short Waves and Meteorology—J. Dufour. (*Bull. Tech. suisse romande*, vol. 79, pp. 121–126; May 16, 1953.) Discussion of tropospheric propagation at wavelengths below 10 m, with particular reference to atmospheric refraction and general meteorological conditions. Observations on Swiss radio links are described.

621.396.812.3.029.62 3695
Fading and Loss of Contact on Ultrashort Waves due to the Presence of Inversion Lay-

ers—J. Voge. (*Compt. Rend. Acad. Sci.*, (Paris), vol. 237, pp. 491–493; Aug. 31, 1953.) On the basis of calculations it is concluded that either the direct or the ground-reflected ray may be suppressed over a direct-visibility path, depending on the heights of the path-terminal points relative to the inversion layer. The types of fading or interference resulting in the different cases are indicated.

RECEPTION

621.3.087.4:621.396.8:551.594.6 3696
Intelligibility Recorder for Radiotelegraphy Signals—S. Silleni. (*Ann. Geofis.*, vol. 6, pp. 137–153; Jan., 1953.) A recorder has been developed for atmospheric-noise measurements on single-channel A1 or F1 type transmissions at 10–50 μ; it can be adapted for other noise measurements. Three voltages are derived. The first (q_S) is proportional to the mean received energy. The second (q_T) represents the energy that would be received in the absence of atmospheric noise. The third (q_B) represents the energy-error level above which an error will be counted, this level being determined from statistical considerations. These three voltages are applied to a circuit which determines the differences $\pm(q_T-q_S)-q_B$. If either difference is positive, a pulse signal is passed to the error-counting circuit actuating the pen recorder. A second counter circuit resets both counters to zero when 1000 signals have been received. Block and circuit diagrams are shown and explained.

621.396.621.54 3697
Design for a Communications Receiver—W. H. Segrott. (*Short Wave Mag.*, vol. 11, pp. 85–96 and 154–160; April/May, 1953.) A description is given, with complete circuit details, of a receiver for the 7-, 14-, and 21-mc bands, designed so that a minimum of test equipment is needed in the construction and alignment. Ganged tuning units are not used. Intermediate frequencies of 5 mc, 465 kc and 50 kc are used, selectivity and signal/ratio being comparable with those of a highgrade commercial receiver. With two converters for the 28-mc and VHF bands, the receiver comprises 9 units, one of which includes a cr tube monitor and signal-strength meter.

621.396.621.54.029.51 3698
Converter for 200 kc/s—C. B. Raithby. (*Wireless World*. vol. 59, p. 487; Oct., 1953.) The converter circuit described comprises a triode-hexode mixer with a crystal-controlled oscillator; crystal frequencies ranging from 3 to 10 mc have been found satisfactory. Reception on 200 kc can be obtained with any reasonably well screened sw receiver.

621.396.622:519.272 3699
Measurements of Detector Output Spectra by Correlation Methods—L. Weinberg and L. G. Kraft. (Proc. I.R.E., vol. 41, pp. 1157–1166; Oct., 1953.) Correlation technique is applied experimentally to determine the power-density spectra of the outputs of linear and square-law detectors. A digital correlator [1237 of 1951 (Singleton)] is used to obtain values of the input and output autocorrelation functions for inputs of filtered noise either alone or combined with a sine wave; these values are compared with the curves calculated from theory.

STATIONS AND COMMUNICATION SYSTEMS

621.39.001.11 3700
The Equivalence of Optimum Transducers and Sufficient and Most Efficient Statistics—G. W. Preston. (*Jour. Appl. Phys.*, vol. 24, pp. 841–844; July, 1953.) A statistical treatment of the problem of recovering the original form of a signal which has become mixed with noise, while preserving information in the Shannon sense. A transducer is discussed which is the physical analogue of a statistic, in the Fisher sense; the properties of the optimum transducer are equivalent to the statistical properties of "sufficiency" (preservation of information) and "efficiency" (maximization of fidelity). The case of a Gaussian signal mixed with Gaussian noise is considered in detail; the maximum-likelihood estimate of the signal is derived and its physical analogue is identified as the Wiener smoothing filter with infinite lag.

621.39.001.11 3701
Correlation versus Linear Transforms—D. A. Bell and M. J. E. Golay. (Proc. I.R.E., vol. 41, p. 1187; Oct., 1953.) Discussion on 1477 of May.

621.39.001.11:061.3 3702
The London Conference, September 1952: Part 1—Applications of the Theory of Information—A. Fromageot. (*Onde élect.*, vol. 33, pp. 473–478; July, 1953.) A review of the subjects discussed which concern telephony and telegraphy. Part 2: 3601 above.

621.39.001.11:517.43 3703
Analysis of Signals and of Linear Transmission Operators—H. Angles d'Auriac. (*HF, Brussels*, vol. 2, pp. 119–138, 162–172 and 179–187; 1953.) Analytical methods of Fourier and Dirac and their application to the determination of the propagation constants of a linear transmission system are explained. An alternative method is to represent the operation of the system by a "linear transmission operator" which may be reduced to elementary operators of "filtering" and "echo" types. The practical significance and application of the method in the case of signals with limited spectrum or finite duration are discussed; an examination of the requirements of a test signal for checking transmission systems indicates the suitability of the "raised-cosine" signal for this purpose.

621.395.44:621.315.052.63 3704
Transmission Considerations—G. E. Burridge and A. S. G. Jong. (*Trans. AIEE*, vol. 70, part II, pp. 1335–1340; 1951. Discussion, p. 1340.) Full paper. Summary noted in 1102 of 1952.

621.395.44:621.315.052.63:621.395.822 3705
A Study of Carrier-Frequency Noise on Power Lines: Parts 1 and 2—R. C. Cheek and J. D. Moynihan. (*Trans. AIEE*, vol. 70, part II, pp. 1127–1133 and 1325–1334; 1951. Discussion, pp. 1133–1134.) Theoretical aspects of the noise problem are discussed and measurement techniques are described. The results of measurements of noise levels on representative power-transmission lines with operating voltages from 23 to 230kv are presented and discussed. Impulsive noise with repetition rates from 50 to 180/seconds was found predominant.

621.396.4 3706
Channel-Spacing Considerations in the 154-174-Mc/s Band—H. E. Strauss. (*Trans. I.R.E.*, pp. 44–57; June, 1953.)

621.396.41 3707
A Report on Channel-Splitting Demonstrations conducted in Syracuse—N. H. Shephard. (*Trans. I.R.E.*, pp. 58–66; June, 1953.)

621.396.41 3708
Commercial Experience with 160-Mc/s–20-kc/s Equipment—D. E. Noble. (*Trans. I.R.E.*, pp. 67–70; June, 1953.) Report of tests carried out on a 20-kc split-channel system.

621.396.41.001.42 3709
Field Test of Split-Channel 50-Mc/s Systems—W. M. Rust, Jr. (*Trans. I.R.E.*, pp. 32–35; June, 1953.)

621.396.41.001.42 3710
Operational Experience with a Split-Channel 50-Mc/s System—J. S. Stover. (*Trans. I.R.E.*, pp. 36–37; June, 1953.)

621.396.5:621.396.8 3711
Comparison of Mobile-Radio Transmission at 150, 450, 900 and 3700 Mc/s—W. R. Young, Jr. (*Trans. I.R.E.*, pp. 71–85; June, 1953.) Reprint. See 823 of March.

621.396.619.16 3712
Deltamodulation, a Method of P.C.M. Transmission using the 1-Unit Code—F. de Jager. (*Philips Res. Rep.*, vol. 7, pp. 442–466; Dec., 1952.) Theory of the method is developed particularly in its relation to information theory. See also 2603 of 1952 (Schouten et al.).

621.396.65:621.396.93 3713
Frequency Economy in Mobile-Radio Bands—K. Bullington. (*Trans. I.R.E.*, pp. 4–27; June, 1953.) Reprint. See 1797 of June.

621.396.65:621.396.931 3714
Technical Considerations governing the Choice of Channel Spacing in Mobile Communication Bands—D. M. Heller. (*Trans. I.R.E.*, pp. 28–31; June, 1953.)

621.396.65:621.396.933 3715
Multi-Station Air-to-Ground Communications—(*Wireless World*, vol. 59, p. 500; Oct., 1953.) A VHF area coverage scheme for New Zealand is described, with control centre at Wellington, alternative control centre at Paraparaumu, transmitting and receiving stations at Mount Egmont and Colonial Knob, and two-way radio links between the last-mentioned station and the others. Each link carries six speech channels for modulating ground-to-air transmitters, an engineers' speech channel, and audio tones for switching and remote control. The link transmissions are frequency modulated, with subcarriers for the ground-to-air traffic amplitude modulated on the ssb system. The ground-to-air transmissions are amplitude modulated.

621.396.712.3 3716
Technical Arrangements in the Cologne Broadcasting Centre—O. Bero. (*Tech. Hausmitt. NordwDtsch. Rdfunks*, vol. 5, pp. 98–108; 1953.) Illustrated description, with block circuit diagrams, of the distribution system linking the various studios and control rooms, and of the control and operating equipment.

621.396.712.3:621.395.625.2/.3].004.5 3717
Supervision of Electroacoustic Equipment in the Cologne Broadcasting Centre—F. Enkel. (*Tech. Hausmitt. NordwDtsch. Rdfunks*, vol. 5, pp. 109–114; 1953.) General description of the arrangements for testing and maintenance of microphones, magnetophones and amplifiers.

621.396.931 3718
The [Belgian] Post-Office Public Ground Mobile Radiotelephone Service—P. Bouchier. (*HF, Brussels*, vol. 2, pp. 173–178; 1953.) A general description of the organization and equipment, with discussion of the frequencies used and the selective calling and secrecy arrangements. Tests made in the Brussels area are reported; the influence of the nature of the terrain is indicated.

621.396.619.001.11 3719
Harmonics, Sidebands and Transients in Communication Engineering, as studied by the Fourier and Laplace Analyses [Book Review]—C. L. Cuccia. Publishers: McGraw-Hill, London, Eng., 465 pp.; 1952. (*Nature*, [*London*] vol. 172, pp. 5–6; July 4, 1953.)

SUBSIDIARY APPARATUS

621-526 3720
Synthesis of Feedback Control Systems by means of Pole and Zero Location of the Closed Loop Function—M. R. Aaron. (*Trans. AIEE*,

vol. 70, part II, pp. 1439–1445; 1951. Discussion, pp. 1445–1446.) A mathematical description of the desired frequency response, based on the location of the poles and zeros of the closed loop function, is given which ensures that the specifications of velocity or acceleration error constant, bandwidth, and relative stability will be met and which provides for acceptable system transient response. Algebraic manipulation yields the transfer function of the main-loop and subsidiary feedback-loop corrective networks required to meet the specifications.

621-526 3721
Servomechanism Transient Performance, from Decibel log Frequency Plots—H. Harris Jr, M. J. Kirby and E. F. von Arx. (*Trans. AIEE*, vol. 70, part II, pp. 1452–1459; 1951. Discussion, p. 1459.)

621-526 3722
Sampled-Data Control Systems Studied through Comparison of Sampling with Amplitude Modulation—W. K. Linvill. (*Trans. AIEE*, vol. 70, part II, pp. 1779–1786; 1951. Discussion, pp. 1787–1788.)

621-526:621.3.016.352 3723
Stability of Varying-Element Servomechanisms with Polynomial Coefficients—M. J. Kirby and R. M. Giulianelli. (*Trans. AIEE*, vol. 70, part II, pp. 1447–1450; 1951. Discussion, p. 1451.)

621-526:621.314.3† 3724
An Improved Magnetic Servo Amplifier—C. W. Lufcy, A. E. Schmid and P. W. Barnhart. (*Elect. Eng., N. Y.*, vol. 72, p. 308; April, 1953.) Digest only.

621.316.072.1/.2 3725
Current and Voltage Regulators—J. Pottier and A. Lavaitte. (*Onde élect.*, vol. 33, pp. 442–452; July, 1953.) A review of the principles of various types of regulator utilizing a reference standard. Systems for low and high power, and for direct and alternating current or voltage, are considered.

621.316.722.1 3726
An Electromechanical A.C. Line-Voltage Stabilizer—D. M. Murray and N. L. Kusters. (*Trans. AIEE*, vol. 70, part II, pp. 1741–1748; 1951.) Description of a stabilizing unit having a short recovery time comparing favorably with that of commercial electronic devices. A temperature-limited diode in a bridge circuit is used to detect the line-voltage variations, and is followed by a phase inverter and a thyratron driving circuit.

621.352.12 3727
Recent Developments in the Field of Electric Cells—J. Pernik. (*Rev. Gén. Élect.*, vol. 62, pp. 294–303; June, 1953.) Improvements in Leclanché-type cells are reviewed and the construction and properties of (*a*) Ag-Mg cells with AgCl depolarizer, (*b*) C-Zn cells with HgO depolarizer, are described.

621.355.9 3728
The Silver-Zinc Accumulator—C. L. Chapman. (*Electronic Eng.*, vol. 25, pp. 422–423; Oct., 1953.) Construction details are described and performance figures given. Types are available with capacities from 0.75 to 60 AH, the corresponding weights ranging from $\frac{3}{4}$ ounce to 1 pound 12 ounces. The temperature limits of operation are discussed.

TELEVISION AND PHOTOTELEGRAPHY

621.39.001.11:[621.396.9+621.397.5 3729
The London Conference, September 1952: Part 2—Radar and Television—Loeb. (*See* 3601.)

621.397 3730
A High-Speed Direct-Scanning Facsimile System—C. R. Deibert, F. T. Turner, and R. H. Snider. (*Trans. AIEE*, vol. 71, part I, pp. 115–121; 1952) Full paper. See 841 of March.

621.397.5:621.39.001.11 3731
Economy of Bandwidth in Television—D. A. Bell. (*Jour. Brit. IRE*, vol. 13, pp. 447–470; Sept., 1953.) The nature of television signals and proposed methods of improving the picture-quality/bandwidth ratio are examined in the light of communication theory; some of the less obvious features of the spectrum generated by conventional scanning methods are discussed. The offset-carrier and "tête-bêché" systems for reducing shared-channel interference are described. Devices for reducing the bandwidth required to accommodate the signal or for increasing the amount of information transmitted with the existing bandwidth are reviewed. 41 references.

621.397.61(410) 3732
Television in Great Britain—K. H. Deutsch (*Funk u. Ton*, vol. 7, pp. 288–297; June, 1953.) A general account, dealing with technical transmission data, program production, studio arrangements, transmitters, and cable and radio links connecting different points of the system.

621.397.611.2 3733
New Developments in the Image Iconoscope—J. C. Francken and H. Bruining. (*Philips Tech. Rev.*, vol. 14, pp. 327–335; May, 1953.) See 2167 of July (Bruining).

621.397.62 3734
Intercarrier-Sound Television Receivers—A. Boekhorst. (*Philips Tech. Commun.*, No. 2, pp. 3–15; 1953.) Reprint. See 857 of March.

621.397.62:621.314.2 3735
I.F. Amplifiers with Bifilar-Wound Coils for Television Receivers—W. Taegar. (*Frequenz*, vol. 7, pp. 57–59; March, 1953.) Equivalent-circuit analysis of bifilar IF transformers (2138 of 1950), showing how the coupling coefficient can be calculated.

621.397.62:621.316.729 3736
The Operation of Slow-Acting Deflection-Synchronization Circuits in Television Receivers—G. W. Kijakowski. (*NachrTech.*, vol. 3, pp. 269–274; June, 1953. German translation of paper in *Radiotekhnika*, 1952, No. 6.) Analysis is given of the process of frequency and phase control of a sine-wave generator by synchronization pulses. The optimum circuit parameter values can be determined from expressions given for the sensitivity of the system to interference by single pulses and the conditions for rapid aperiodic restoring of synchronism. Experiments confirmed the theory.

621.397.62:621.385.832 3737
A Short-Length Direct-View Picture-Tube—J. L. H. Jonker. (*Philips Tech. Rev.*, vol. 14, pp. 361–367; June, 1953.) Various known methods are discussed for reducing the length of cr tubes for television receivers without decreasing the size of the picture. A description is given of an experimental tube with its neck bent through an angle >90 degrees. A permanent magnet is used to bend the beam correspondingly. The usual scanning-deflection angle of 65 degrees is used.

621.397.62:621.397.335 3738
Flywheel Synchronization—B. T. Gilling. (*Wireless World*, vol. 59, p. 495; Oct., 1953.) A note of modifications made to the circuit previously described (1499 of May) consequent on the incorporation of a multivibrator sawtooth generator.

621.397.62.002 3739
The Production of Television Reviewers—F. Allen. (*Jour. Brit. IRE*, vol. 13, pp. 383–398; Aug., 1953.) An account is given of labor-saving methods in use in a particular factory for the quantity production of television components; testing, assembly and packing processes are described.

621.397.621.2:535.623 3740
Rotating-Screen Color TV Tube—I. Rehman, E. Singer and C. S. Szegho. (*Electronics*, vol. 26, pp. 214–222; Sept., 1953.) To overcome the appreciable light absorption of color-filter wheels used in front of the cr tube in sequential systems, a continuously pumped projection tube has been developed within which is mounted a tricolor segmented fluorescent disk revolving at 1800 rpm. The disk has a diameter of $7\frac{1}{2}''$. Phosphors with decay-time constants of the order of 2.7×10^{-6} seconds are required if high resolution is to be maintained; those used for flying-spot cr tubes are suitable. Measures to increase available light output are considered.

621.397.621.2:621.316.86 3741
Frame-Deflection Circuit with VDR [voltage-dependent] Resistor—H. H. van Abbe and A. Boekhorst. (*Electronic Applic. Bull.*, vol. 13, pp. 101–108; July, 1952.) The V/I relation for the particular type of resistor used is given by $V=cI\beta$, where β ranges from 0.16 to 0.30. Such a resistor is included in the network coupling the frame oscillator to the output stage, to linearize the sawtooth current supplied to the deflection coils; its operation is frequency-independent. A complete frame-deflection circuit diagram is shown.

621.397.645.026.445 3742
An Experimental 100-kW Television Output Stage—D. Zaayer. (*Philips Tech. Rev.*, vol. 14, pp. 345–357; June, 1953.) A detailed account is given of experimental work on an output stage required to have a response level to within 1 db over a frequency band of width 6 mc, for 625-line transmissions. High-level modulation is used in a push-pull grounded-grid circuit tunable from 48 to 68 mc and preceded by a 20-kw driver stage, two sub-driver stages and a low-power variable-frequency oscillator.

621.397.645.36 3743
Push-Pull Amplifiers for Increased Video Output—A. Newton. (*Electronics*, vol. 26, pp. 228., 236; Sept., 1953.) Improved linearity and higher output are among the advantages of push-pull amplifiers used as video output stages. Design problems involved are discussed, particularly dc restoration. Three alternative circuits are shown.

621.397.645.371.029.4/.5 3744
Special Amplifiers for Television—J. Sánchez-Cordovés. (*Rev. Telecommun.*, vol. 9, pp. 30–36; June, 1953.) Wide-band amplifiers for television transmitters are considered. The particular types discussed are variants of the cathode repeater and the shunt-regulated cathode follower for high-level modulators.

621.397.8 3745
The Relation between Transient Response and Picture Quality in Television Transmission Systems—J. Müller. (*Fernmeldetech. Z.*, vol. 6, pp. 320–324; July, 1953.) The subjective limits of the perception and the tolerance of various forms of distortion were related to the measured transient response of the system. The tolerable limits of the transient response characteristics, measured as the distortion of a rectangular wave, are tabulated. See also 2063 of 1949 (Kell and Fredendall).

TRANSMISSION

621.396.61:621.396.712 3746
Modern Transmitter for A.M. Broadcasting—A. A. McKenzie. (*Electronics*, vol. 26, pp. 130–136; Sept., 1953.) Illustrated descrip-

tion of the 50-kw transmitter at WNEW, New York, a new station which operates 24 hours a day on 1.13 mc. Various techniques are used to ensure uninterrupted operation.

TUBES AND THERMIONICS

621.314.7:546.289 3747
Bandwidth Limitation of Junction Transistors—A. J. W. M. van Overbeek and F. H. Stieltjes. (*Wireless Eng.*, vol. 30, p. 261; Oct., 1953.) Theory given by Steele (881 of March) makes it possible to calculate a fundamental limit to the wide-band figure-of-merit of junction transistors, if the output capacitance is not taken into account. It is calculated that the separation between emitter and collector corresponding to a figure-of-merit of 1 ma per volt per pF is 3 μ for a *p-n-p* transistor and 4.4 μ for a *n-p-n* transistor.

621.383.27 3748
Photomultipliers and the Detection of Nuclear Particles—H. Dormont and E. Morilleau. (*Le Vide*, vol. 8, pp. 1344–1352; May, 1953.) Properties required in photomultipliers for scintillation counting are stated. Measuring procedure is indicated for verifying that conditions in respect of gain, matching of photocathode to crystal, and stability are satisfactory. The construction and characteristics are described of a photomultiplier designed by the Laboratoires d'Electronique et de Physique appliquées; its performance is close to that of RCA Type-5819

621.385.004.15 3749
Reliability of Filamentary Subminiature Tubes—R. Wood. (*Proc. NEC*, vol. 8, pp. 562–567; 1952.) Discussion of design factors resulting in improved reliability as regards maintenance of characteristics during life and under conditions of shock or vibration.

621.385.029.6:621.396.615.14 3750
Traveling-Wave-Tube Oscillators—H. R. Johnson and J. R. Whinnery. (*Trans. IRE*, p. 24; June, 1953.) Correction to paper abstracted in 1872 of June.

621.385.029.6.016.22 3751
Factors affecting Traveling-Wave-Tube Power Capacity—C. C. Cutler and D. J. Brangaccio. (*Trans. IRE*, pp. 9–23; June, 1953.) The amount and distribution of attenuation in the circuit limit the power output capability of a traveling-wave tube. Empirical design criteria, based on experimental results, are given. These specify the attenuation distributions resulting in a minimum length of active circuit and a minimum gain consistent with maximum efficiency. A beam efficiency of 11 per cent and over-all anode efficiency of ~20 per cent were obtained in a tube operating at 4 kmc and giving 8 w output power. Efficiency as a function of the gain, space charge and attenuation is considered.

621.385.029.64/.65 3752
Starting Currents in the Backward-Wave Oscillator—L. R. Walker. (*Jour. Appl. Phys.*, vol. 24, pp. 854–859; July, 1953.) In this type of oscillator an electron stream interacts with a particular spatial harmonic of one of the transmission modes of a periodic structure such as that used in a travelling-wave amplifier [547 of 1952 (Millman)]. A formula is derived for the starting current, taking account of space-charge effects. The analysis shows clearly that backward-wave oscillation is an interference phenomenon.

621.385.029.64/.65:513.647.1:621.317.336 3753
Helix Impedance Measurements using an Electron Beam—D. A. Watkins and A. E. Siegman. (*Jour. Appl. Phys.*, vol. 24, pp. 917–922; July, 1953.) Measurements were made on a helix in a specially constructed traveling-wave valve. The impedance for the fundamental mode was less by a factor of 0.8–0.3 than that calculated on the basis of Pierce's sheath model. Observations of other modes verify Sensiper's analysis which predicts that certain values of phase constant cannot apply in the case of a single-wire helix. A relation between the impedance for one space-harmonic component and that for its fundamental is derived. The operation of the system as a backward-wave oscillator, continuously tunable over the range 1.5–4.3 kmc, is described.

621.385.029.64 3754
A Method for the Reduction of the Noise-Factor of Travelling-Wave Valves—H. Schnitger and D. Weber. (*Fernmeldetech. Z.*, vol. 6, pp. 302–310; July, 1953.) The electron beam passes through an auxiliary delay line before entering the main delay line. Due to the interaction between the beam and the wave in the auxiliary delay line, a velocity-modulation noise component is added to the density-modulation noise component; these components cancel one another partially or completely, if the auxiliary delay line is designed correctly. A numerical example is given to illustrate the application of the formula derived; at λ of 7.2 cm the noise factor is 8.5. It is theoretically possible to reduce the noise factor to about 1.2 by this method.

621.385.032.216 3755
Characteristic Shifts in Oxide-Cathode Tubes—W. P. Bartley and J. E. White. (*Trans. AIEE*, vol. 71, part I, pp. 43–49; 1952.) Full paper. See 3599 of 1952.

621.385.1 3756
A Rubber-Membrane Model for Tracing Electron Paths in Space-Charge Fields—G. A. Alma, G. Diemer and H. Groendijk. (*Philips Tech. Rev.*, vol. 14, pp. 336–344; May, 1953.) A rubber-membrane method is described in which the effect of space charge on the field is simulated by applying pressure from underneath the membrane. Experiments illustrating various electron-optical phenomena are discussed and the application of the method in the design of a microwave triode is indicated.

621.385.13 3757
An Approximation to the Three-Halves Power Law for a Finite Cathode in a Uniform Field—I. I. Levintov. (*Compt. Rend. Acad. Sci., U.R.S.S.*, vol. 85, pp. 1247–1250; Aug. 21, 1952. In Russian.)

621.385.2/.3:621.396.822.029.6 3758
The Noise of Electronic Valves at Very High Frequencies: Part 1—The Diode. Part 2—The Triode—G. Diemer and K. S. Knol. (*Philips Tech Rev.*, vol. 14, pp. 153–164; Dec., 1952 and vol. 14, pp. 236–244; Feb., 1953.) A more detailed discussion than that noted in 907 of March (Diemer).

621.385.3:621.365.54/.55† 3759
The Design of High-Power Vacuum Tubes for Industrial Heating Applications—H. D. Doolittle. (*Trans. AIEE*, vol. 70, part II, pp. 1934–1937; 1951.)

621.385.832 3760
Direct-Viewing Memory Tube—S. T. Smith and H. E. Brown. (Proc. I.R.E., vol. 41, pp. 1167–1171; Oct., 1953.) The storage tube described by Haeff (319 of 1948) is modified by using a mesh-type storage screen in combination with a fluorescent screen at relatively high potential. Electrons passing through positively charged areas of the mesh are accelerated to produce an intensified bright image of the charge pattern. Contrast, writing speed, resolution, persistence, and the provision of an electrical output are discussed.

621.385.832:535.371.07 3761
Monolayer Fluorescent Screens—L. R. Koller. (*Jour. Opt. Soc. Amer.*, vol. 43, p. 620; July, 1953.) Details are given of a method of preparing cr-tube screens of monomolecular thickness; the phosphor grains are first coated with a water repellent, e.g., a silicone.

621.385.832:621.318.572 3762
A Decade Counter Tube for High Counting Rates—A. J. W. M. van Overbeek, J. L. H. Jonker and K. Rodenhuis. (*Philips Tech. Rev.*, vol. 14, pp. 313–326; May, 1953.) A description of the tube [3614 of 1952 (Jonker et al.)] is given, and a new circuit is discussed by means of which 30,000 pulses per second can be counted.

621.387:621.318.572 3763
The Principles and Method of Operation of some Modern Gas-filled Counter Tubes—A. B. Thomas. (*Jour. Brit. IRE*, vol. 13, pp. 414–419; Aug., 1953 and Proc. IRE (Australia, vol. 13, pp. 311–315; Aug., 1952.) Four types of discharge possible in gas-filled tubes are discussed; the conditions under which each occurs are indicated. The methods of operation of the remtron, dekatron and nomotron are described.

621.396.615.141.2 3764
Currents and Space Charges in the Magnetron—K. Fritz. (*Arch. elekt. Übertragung*, vol. 7, pp. 338–340; July, 1953.) Analysis is developed starting from the equation of motion of the optimum-path electron previously derived (2592 of 1952). From consideration of the radial component of electron motion a theoretical upper limit for the anode current is found; this value is nearly attained in operation. Experimental investigation of the tangential component is more difficult. The theoretical results obtained do not depend on electron bunching processes, i.e., only the direction and velocity of the electrons are involved. The theory is applicable both to ordinary and to inverted magnetrons.

MISCELLANEOUS

621.39:061.4 3765
Radio Show Review—(*Wireless World*, vol. 59, pp. 446–461; Oct., 1953.) Report on design tendencies revealed at the 20th National Radio Exhibition (3163 of October). Main attention is devoted to television receivers, but sound receivers, sound reproducers, valves and industrial electronic applications are also discussed. See also *Wireless Eng.*, vol. 30, pp. 255–260; Oct., 1953.

*Microline** Instruments

ince 1938, when Sperry sponsored the development of the Klystron, this company has xtended its application to tubes for low, medium and high-power applications. As a pioneer n microwave measuring techniques, Sperry has developed Microline instruments which nclude every type of device essential to precise measurement in the entire microwave field. Research and development are continuous at Sperry and the results are always available to you.

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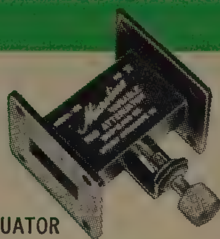
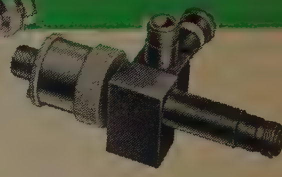
Microline

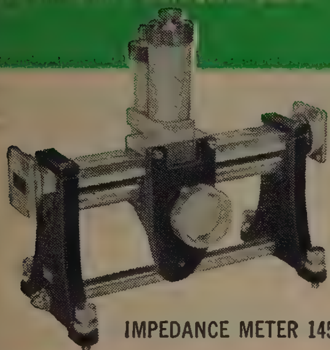


ATTENUATOR 152A

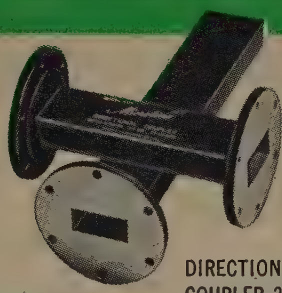
DETECTING SECTION 364



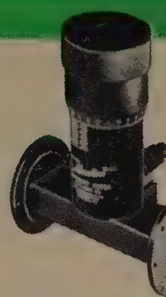
MIXER 337C



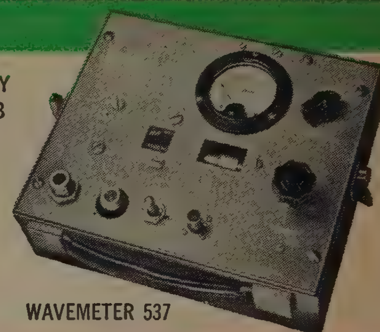
IMPEDANCE METER 145



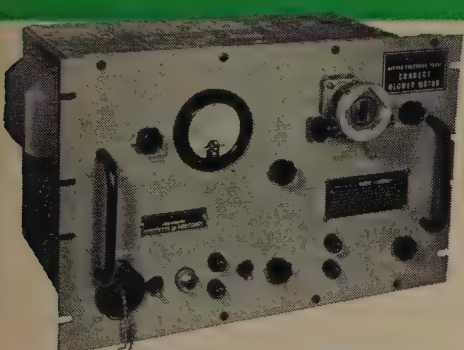
DIRECTIONAL COUPLER 209



FREQUENCY METER 28B



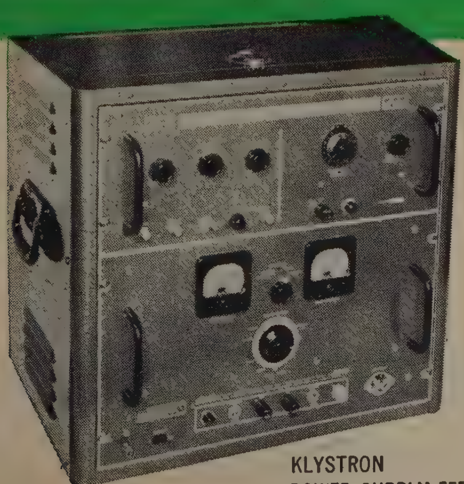
WAVEMETER 537



RADAR RANGE CALIBRATOR UPM-11

VSWR TEST SET 539

RADAR TEST SET 38A



KLYSTRON POWER SUPPLY 555

SPERRY GYROSCOPE COMPANY

Industrial Engineering Notes*

Technical

More Basic research and less development work under transfer funds from other government agencies. That will be the "new look" for the National Bureau of Standards and its Electronics Division, if recommendations of the Scientists' Committee for Evaluation of the Bureau's functions and operations are carried out. The Committee's report, which became available this week, points out that the Electronic Division "has a capable staff and is performing useful functions." But with 98 per cent of its funds furnished by other agencies during 1953, the Division has been molded "into a consulting, research, and development organization to serve other government agencies. Thus," the report said, "the Electronics Division is not adequately responding to the needs of science and industry." The establishment of a group on vacuum tubes and transistors "which devotes itself to standardization, reliability, testing and standards on a national basis," was recommended. It also was suggested that an advisory committee be established for the division and that larger funds be made available through direct appropriation to the NBS so that it can work more on programs of basic research, and less on research and development activities for other government agencies which are not related to the basic NBS activities. . . .

The Office of Technical Services, Department of Commerce, in its October issue of the "Bibliography of Technical Reports," includes several research studies in the electronics field. The following, of interest to the electronics industry, can be purchased from the Photoduplication Section, Library of Congress, Washington

(Continued on page 88A)

*The data on which these Notes are based were selected by permission from *Industry Reports*, issues of October 23 and 30, and November 6 and 13, published by the Radio-Electronics-Television Manufacturers Association, whose helpfulness is gratefully acknowledged.

Professional Group on Ultrasonics Engineering

One of the greatest assets of the IRE Professional Group plan is its flexibility in being able to serve equally well the many branches of the radio field, regardless of how new, small, or specialized they may be. This is convincingly demonstrated in the case of the newly formed Ultrasonic Engineering Group.

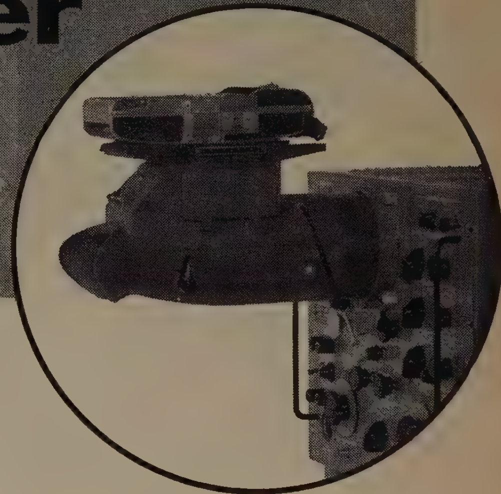
Although a relatively young field, ultrasonics already embraces many diverse fields. In the laboratory ultrasonic techniques are used for studying the properties of gases, liquids, and solids. Marine applications include ultrasonic depth indicators and underwater object locators. In the medical field ultrasonic diathermy instruments, tumor locators, dental caries locators, and even a device to replace the dentist's drill are being investigated and developed. In industry ultrasonics is finding application in nondestructive testing of materials, acceleration of chemical reactions, emulsification, coagulation, and sterilization. Ultrasonic delay lines and electromechanical filters are being used in radio, radar, and digital computers. There may one day be ultrasonic washing machines.

How then is one to keep abreast of these tremendous strides? Only by receiving an authoritative technical publication devoted exclusively to this subject; only by attending meetings at which recent advances are discussed; only by exchanging ideas with other workers in the field.

It was with this purpose that the Ultrasonics Engineering Group was formed a few short months ago. Plans for these activities have already reached the final stage, to be inaugurated early in 1954. Once again a specialized need has been met successfully by an IRE Professional Group.

W. R. G. Baker
Professional Group Chairman

Efficient Economical Camera Adapter



Now available on

Lavoie Oscilloscope (Model LA-239C)

The popular Lavoie Oscilloscope LA-239C has had a new plus feature added: The ability to mount the Lavoie Camera Adapter quickly and without modification. The Camera Adapter may be readily installed by removing the bezel, and securing the Adapter with four knurled nuts supplied on the panel. Already widely used in the development of radar and guided missiles, this new feature makes the LA-239C Oscilloscope a more valuable tool than ever.

NOTE: When ordering the LA-239C Oscilloscope primarily for photographic use, a P-11 Screen CRT is recommended. Specify type of phosphor desired.

- **Long persistence trace (P-2 phosphor)**
- **medium persistence trace (P-1 phosphor)**
- **blue photographic trace (P-11 phosphor) available.**

CAMERA ADAPTER DATA: Calibrated illuminated scale—1/50, 1/25, 1/2, 1, 5 secs. at f2.8
32 pictures per roll @ 5 cents each—a saving of 50 cents per roll.

OSCILLOSCOPE DATA

Wider Bandwidth: Complex waves from 5 cycles to 15 megacycles. Sine waves from 3 cycles to 20 megacycles.

Extended Sweep Frequencies: Linear from 10 cycles to 20 megacycles internally synchronized. Triggered sweep, from a single impulse to irregular pulse-intervals up to as high as 6 megacycles.

Square Wave Response: Rise time 0.022 microseconds, only 5% droop on flat-topped pulses as long as 30,000 microseconds duration.

Greater Stability: Electronically regulated power supplies throughout to maintain accuracy and constant operation under varying line conditions or line surges. Surges on the line from which Model LA-239C is being powered can be displayed without distortion.

Higher Signal Sensitivity: Maximum sensitivity without Probe: 10.4 millivolts. With Probe: 100 millivolts. (Maximum signals, 125 V. Peak and 450 V. Peak respectively.)

Timing Markers: Interval: Markers of 0.2, 1, 5, 20, 100, 500 or 2,000 microseconds may be superimposed on the trace for the accurate measurement of the time base.

Voltage Calibration: Signal amplitude is referenced to a 1,000 cycle square wave (generated internally) the amplitude of which is controlled by a step-and-slide attenuator calibrated in peak volts. (A jack is provided to deliver 30 V. Peak for use in calibrating other instruments.)

Sweep Delay: Any portion of the sweep longer than a 5 microsecond section may be expanded by 10:1 for detailed study of that portion of the signal.

Power Source: 110 to 130 V. AC from 50 to 1,000 cycles. 295 Watts. (Fused at 4 amperes.)

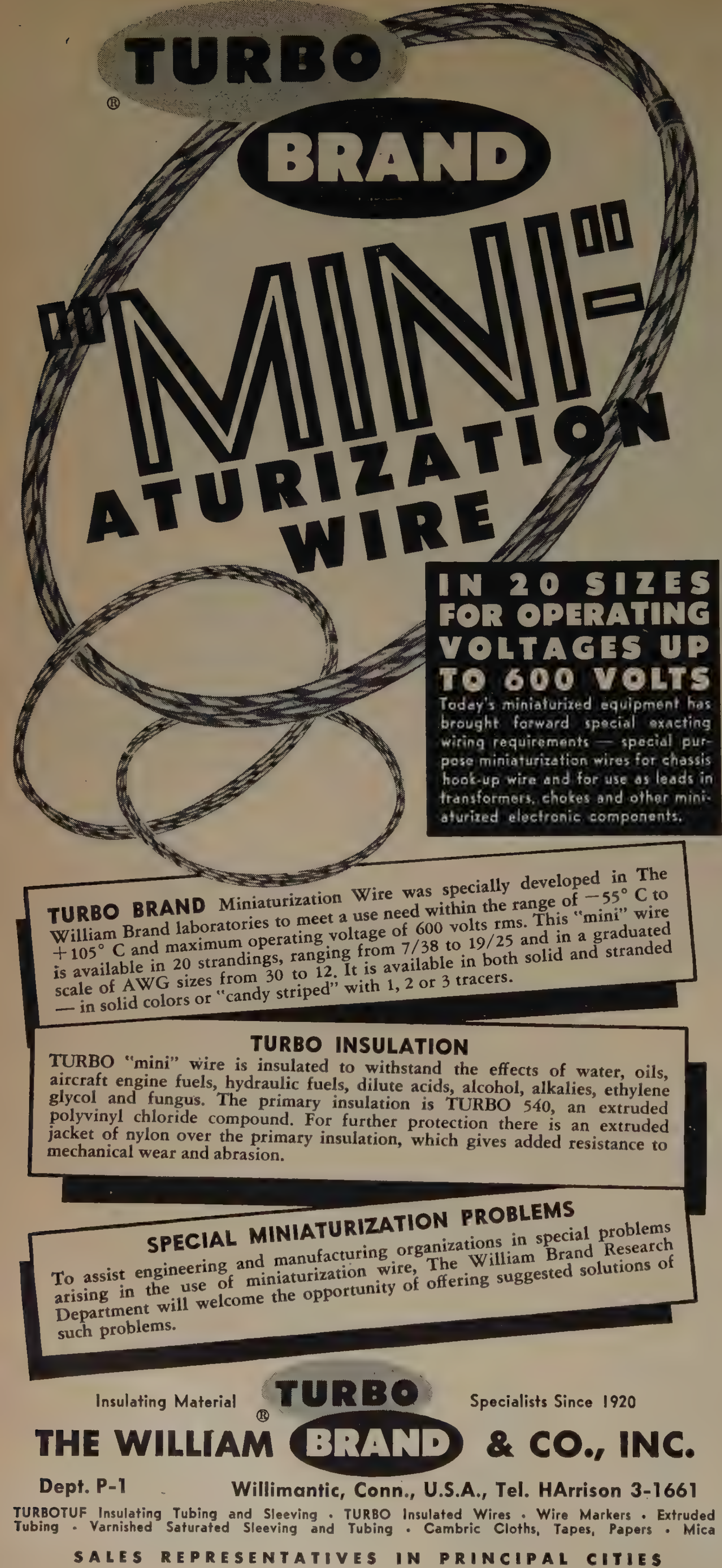
Dimensions: In Bench Cabinets: 19½ in. wide, 15¼ in. high, 16¾ in. deep. In Rack Mounting (with cabinet removed to fit standard relay rack): 19½ in. wide, 14 in. high.

Lavoie Laboratories, Inc.

UHF

MORGANVILLE, NEW JERSEY

Designers and Manufacturers of Electronic Equipment



Industrial Engineering Notes

(Continued from page 84A)

25, D. C., for the reported price:

"Admittance of High-frequency Gas Discharge," PB 110572, microfilm, $1.25; photostat, $1.25.

"Axially Symmetric Electron Beam and Magnetic Field Systems," PB 110527, microfilm, $3.50; photostat, $10.

"Coding with Linear Systems," PB 110607, microfilm, $1.25; photostat, $1.25.

"Deionization Measurements of Grid-Controlled Thyratrons," PB 110570, microfilm, $1.75; photostat, $2.50.

"Effect of Magnetic Field on the Breakdown of Gases at Microwave Frequencies," PB 110513, microfilm, $1.75; photostat, $2.50.

"Electrons in Perturbed Periodic Lattices," PB 110577, microfilm, $2; photostat, $3.75.

"High Frequency Ultrasonics," PB 110523, microfilm, $1.75; photostat, $2.50.

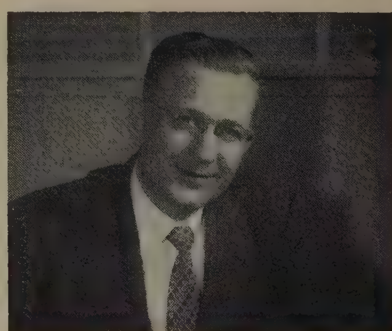
"Measurement of Electron-ion Recombination," PB 110521, microfilm, $1.25; photostat, $1.25.

"Microwave Absorption Spectrum of Oxygen," PB 110599, microfilm, $1.25; photostat, $1.25.

"Optical Detection of Radio-frequency Resonance," PB 110567,

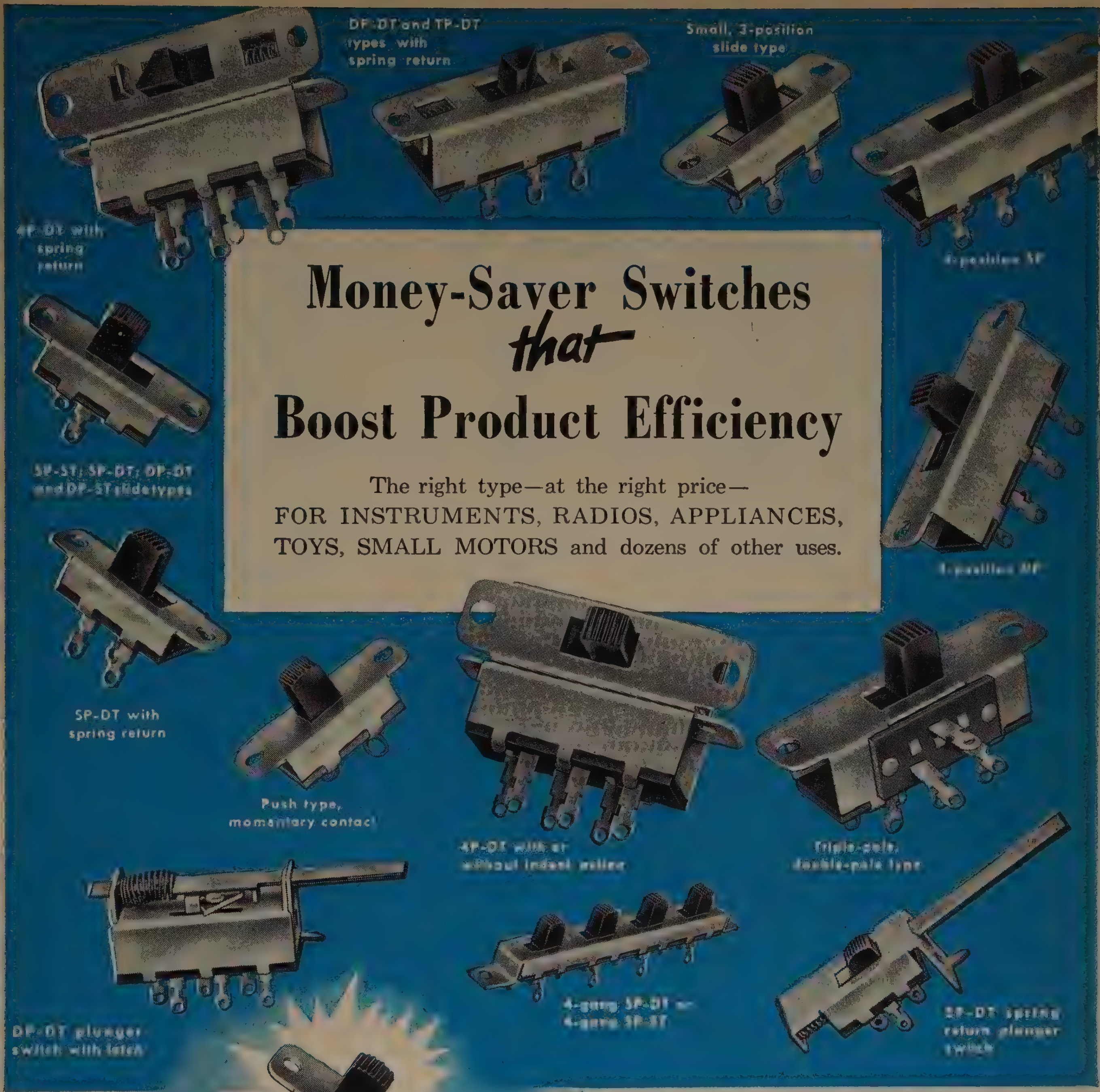
(Continued on page 90A)

Rustad Made General Manager at Crosby Laboratories



Arthur C. Rustad was recently promoted to General Manager of **Crosby Laboratories, Inc.**, engineering, development and production firm of electronic communication equipment at Hicksville, L. I., New York.

Before joining the Crosby organization, Mr. Rustad was with the engineering staff of Press Wireless, Inc., and Press Wireless Mfg. Co.



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The right type—at the right price—
FOR INSTRUMENTS, RADIOS, APPLIANCES, TOYS, SMALL MOTORS and dozens of other uses.

TOPS FOR FRACTIONAL H.P. MOTORS
3-ampere types—SP-ST or SP-DT

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Electronic Components Division

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FIXED AND VARIABLE RESISTORS • SPECIAL RESISTORS • CERAMAG® (ferrite) CORES • IRON CORES • CHOKE FORMS • GA "GIMMICK" CAPACITORS, etc.

Industrial Engineering Notes

(Continued from page 88A)

microfilm, $1.25; photostat, $1.25.

"Mode Control and Operating Voltages of Interdigital Magnetrons," PB 109792, microfilm, $2; photostat, $3.75.

"Signal-to-Noise Ratios in Bandpass Limiters," PB 110609, microfilm, $1.75; photostat, $2.50.

. . . **In the November issue of the "Bibliography of Technical Reports," the following research studies in the electronics field were published.** They can be purchased from the Photoduplication Section, Library of Congress, Washington 25, D. C., for the reported price:

"Circumferential Gap in a Circular Waveguide Excited by a Dominant Circular-Electric Wave," PB 110831, microfilm, $2.25; photostat, $5.

"Considerations in the Design of a Toroidal Tube and Discharge Circuit for Producing a Large Induced Current in a Gas," PB 110825, microfilm, $1.75; photostat, $2.50.

(Continued on page 128A)

Personnel News

During the summer **Erie Resistor Corp.**, Erie, Pa., manufacturer of electonic components and custom molded plastics, named Allen K. Shenk and Jerome D. Heibel to be Vice Presidents, according to Mr. G. Richard Fryling, President of the company.

Mr. Shenk was named Vice President in charge of Sales. He joined Erie in 1942 from W. S. Hill Company, Pittsburgh, where he had been associated for twelve years, to become Assistant Sales Manager of the Electronics Division. Mr. Shenk is a graduate of Princeton University.

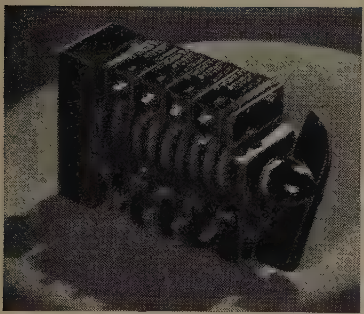
Mr. Heibel has been appointed Vice President in charge of Research and Engineering.

DIGEST

TIMELY HIGHLIGHTS ON G-E COMPONENTS

Withstands vibration

Now the improved General Electric hermetically sealed relay withstands vibration forces of 10g from 10 to 500 cycles per second, offers extra protection against permanent breakdown due to voltage surges. Coil ratings up to 10,000 ohms. Contact configurations available include 4-pole double-throw and 6-pole single throw. See Bulletin GEA-5729.



Controls 20 circuits

Compact, lightweight and easy to mount, these G-E cam-operated selector switches help solve many intricate circuit-combination or sequencing problems . . . control from one to 20 circuits, in any operating sequence within the limits of 12 positions . . . operate at altitudes up to 50,000 feet, and in temperatures from 200 F to −70 F. Check Bulletin GEA-4493.

Quickly locates shorts

Minimize the hazards of short circuits quickly, easily with General Electric low-voltage coil testers. These portable units are designed to test coils before assembly in relays, radios, small transformers and instruments. They maintain accurate on-the-spot service for long use. Can also be used to detect open circuits. See Bulletin GEC-964.

G-E analog plotter helps solve complex field problems — fast

Now you can simplify and speed up those complex field studies by using General Electric's analog field plotter. By means of electric current flow patterns set up in a sheet of thin conducting paper, over-all operation of plotting in two dimensional fields is greatly simplified. Problems in electrostatics, electromagnetics, and many other fields are rapidly solved with this sensitive, versatile plotting board and the complete package of components necessary for making field studies. It needs only low-voltage d-c supply, which eliminates shock hazard, and is not affected by line-voltage variations. Explanation and instructions are covered in a 50-page manual accompanying the plotter. For full details, see Bulletin GEC-851.

EQUIPMENT FOR ELECTRONIC MANUFACTURERS

Components

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Dynamotors
Capacitors
Transformers
Pulse-forming networks
Delay lines
Reactors
Thyrite material
Motor-generator sets
Inductrols
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Fractional-hp motors
Rectifiers
Timers
Indicating lights
Control switches
Generators
Selsyns
Relays
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Terminal boards
Push buttons
Photovoltaic cells
Glass bushings

Development and Production Equipment

Soldering irons
Resistance-welding control
Current-limited high-potential tester
Insulation testers
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Photoelectric recorders
Demagnetizers

General Electric Company, Apparatus Sales Division
Section B667-27, Schenectady 5, New York

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√ for reference only   X for planning an immediate project

☐ GEA-4138 Thyrite Resistance Material
☐ GEA-4493 Selector Switches
☐ GEA-5729 Hermetically Sealed Relays
☐ GEA-5777 Drawn-oval Capacitors
☐ GEC-851 Analog Field Plotter
☐ GEC-964 Low-voltage Coil Tester

Name____________________

Company____________________

City____________________ State______

PROFESSIONAL GROUP MEETINGS

Reports from Chapters

Audio

The Albuquerque-Los Alamos Chapter of the Professional Group on **Audio** met on September 24 at the Coronado Club, Sandia Base, Albuquerque, N. M., under the chairmanship of A. M. Garblik. D. V. Couden and C. A. Smith presented papers entitled "Design Criterion for Crossover Networks" and "A Specific Crossover Network Design Example," respectively. The papers were discussed by the members present, and there was also a demonstration of several types of phonograph transducers. This Chapter also met on October 13 at the Coronado Club, Sandia Base, to hear Chester R. Brown, Instructor at the University of New Mexico, who spoke on cabinet design and finish. A discussion of this subject by the members followed his talk.

The San Diego Chapter of the Professional Group on Audio met on October 3 at the San Diego Hotel, San Diego, Calif., for a high fidelity audio equipment demonstration meeting. The demonstration was in operation from 9 A.M. to 9 P.M. to permit everyone to have a chance to see and hear the equipment at his leisure. The demonstration was set up especially to help those who may have had some difficulty in determining which of the numerous loud speakers and/or enclosures would most satisfactorily meet their personal requirements, from a performance versus cost standpoint. All other components, pickups, turntables, amplifiers, etc. of a complete audio system were also displayed and demonstrated. The rooms in which the demonstrations were held are about the size of the average living room, so it was possible to approximate rather closely performances that would normally be expected in the average home living room. The preliminary arrangements, the setting up of the equipment and the actual operating of the equipment were handled by the members of the Audio Chapter.

The Boston Chapter of the Professional Group on Audio met on November 3 at the Hayden Lounge of the Massachusetts Institute of Technology, Cambridge, Mass. Walter Lawrence of the Signals Research and Development Laboratory, Christchurch, England, and Kenneth N. Stevens, of M.I.T. spoke on Electronic Speech Synthesis. Two speech synthesizers of independent design were described and demonstrated. General consideration was given to the application of such devices in speech-compression systems.

Electronic Computers

The San Francisco Chapter of the Professional Group on **Electronic Computers** met on October 7 in Studio A, KNBC, San Francisco, Calif. The meeting was under

(Continued on page 96A)

PROFESSIONAL GROUP MEETINGS

(Continued from page 94A)

the chairmanship of T. H. Meisling. D. H. Lehmer of the University of California presented a paper entitled "Eight Years after ENIAC."

The Philadelphia Chapter of the Professional Group on Electronic Computers met on October 21 at the Franklin Institute in Philadelphia, under the chairmanship of John M. Broomall. Dr. Samuel Lubkin of the Underwood Corporation presented a paper entitled "The Elecom 100 Series Computers." In his talk Dr. Lubkin described the construction and basic features of the 100 series computers. He also described the input and output equipment, storage systems, component parts, and number system. He illustrated the talk with slides, sample components, and a moving picture of computer operation and testing. Also described in lesser detail were the Elecom 120 and 125 machines. Dr. Lubkin ended the talk with a twenty-minute discussion period.

The Washington Chapter of the Professional Group on Electronic Computers met on October 7 at the PEPCO Auditorium, Washington, D. C., under the chairmanship of C. V. L. Smith. A. W. Holt of the National Bureau of Standards spoke on "The Diode Capacitor Memory." The Washington Chapter also met on November 4 at the PEPCO Auditorium to hear Professor Morris Rubinoff of the Moore School of Electrical Engineering of the University of Pennsylvania present a paper entitled "Digital Computers for Real-Time Simulations and Control."

The Boston Chapter of the Professional Group on Electronic Computers met on November 5 at the Jefferson Physical Laboratory of Harvard University, under the chairmanship of Bernard M. Gorson. Dr. Howard Aiken, Director of the Computation Laboratory of Harvard University gave a paper entitled "Automatic Computers." Following the meeting, the audience was invited to examine the Mark IV Computer in the Computation Laboratory.

Aeronautical and Navigational Electronics

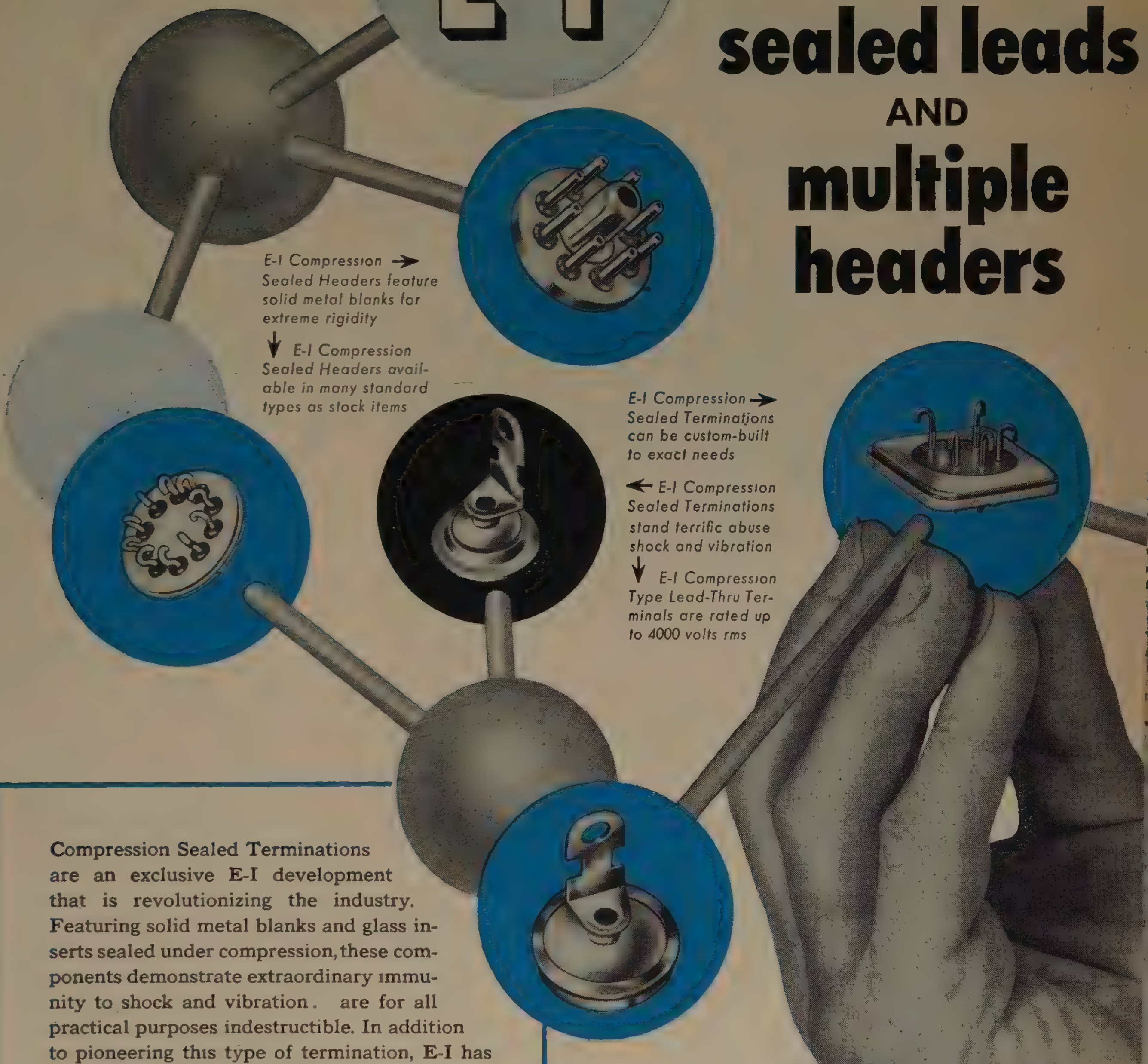
The Dayton Chapter of the Professional Group on Aeronautical and Navigational Electronics met on November 5 at the Dayton Biltmore Hotel, under the chairmanship of M. Jacobs. David Feldman, of Polytechnic Research and Development Co., Brooklyn, N. Y., presented a paper on "Magnetic Amplifiers and Their Application in the Aircraft Industry." Low level magnetic amplifiers with d-c output were described and typical design and production problems outlined. The extension of present practice towards the use of higher carrier frequencies was noted and research towards decreasing the response time was described.

(Continued on page 98A)

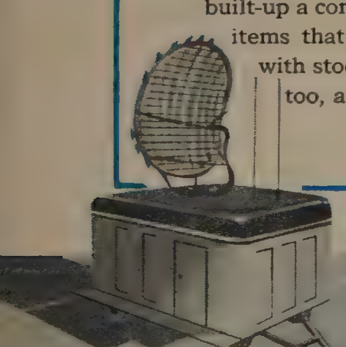
Build-up for Super-Rugged Service –

NEW E-I COMPRESSION

sealed leads AND multiple headers



Compression Sealed Terminations are an exclusive E-I development that is revolutionizing the industry. Featuring solid metal blanks and glass inserts sealed under compression, these components demonstrate extraordinary immunity to shock and vibration . are for all practical purposes indestructible. In addition to pioneering this type of termination, E-I has built-up a comprehensive line of standardized items that solve most terminal problems with stock item economy. Custom types, too, are available on short notice.



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PROFESSIONAL GROUP MEETINGS

(Continued from page 96A)

Electron Devices

The New York Chapter of the Professional Group on **Electron Devices** met on November 24, 1953 at the Engineering Societies Building, New York, N. Y. D. E. Nelson, Tube Department, RCA Victor, spoke on "A High-Power CW Magnetron," and Wen Yuan Pan, Manager of the the UHF and Transistor Circuits Group of RCA Victor, spoke on the "Investigation of UHF Amplifier Operation." Mr. Nelson described a developmental 10 kw continuous wave magnetron tunable over the range of 785 to 845 mc. Mr. Pan discussed some essential properties of amplifiers for operation in the uhf TV band with particular reference to stability, gain, and noise factor. Types of tubes investigated included planar, cylindrical and miniature types.

Medical Electronics

The San Francisco Chapter of the Professional Group on **Medical Electronics** met on October 27, 1953 at the Physics Department, of Stanford University under the chairmanship of Albert J. Morris. Dr. Robert R. Newell and Dr. E. L. Ginzton, both of Stanford University presented a paper titled "Methodology in Measuring Cardiovascular Phenomenon." Dr. Newell's thesis was that although any therapeutic equipment certainly would have an area of usefulness, one should not expect revolutionary things to happen with them; the linear accelerator is no exception. Dr. Ginzton pointed out that the main thing that the medical profession hoped to accomplish with the higher energy linear accelerators was to get greater localization of the irradiation and to get less damage to normal tissue. Also at the higher energy levels the use of direct irradiation by electrons seemed feasible.

The Buffalo-Niagara Chapter of the Professional Group on Medical Electronics met on November 4 at the General Hospital, Buffalo, New York. Alan Lesswing and George Pfetch spoke on electronic plethysmography. A discussion of this subject, which included a practical demonstration of their impedance bridge, was participated in by the entire group. A fundamental interest was the joint attempt by a senior medical student and an electronic engineer (a reaction in which this Chapter is attempting to act as a catalyst) and the wide, practical possibilities indicated by their demonstration. The following men were elected officers of the Chapter to serve for the succeeding year: Karl Swartzel and Arthur MacNeill, Co-Chairmen, and Robert H. Ellis, Secretary.

Radio Engineering Show
Kingsbridge Armory
BRONX, N.Y.
March 22-25, 1954

SECTION MEETINGS

AKRON

"Radio Astronomy," by Sol Matt, Radio Astronomy Group, Ohio State University; October 22, 1953.

ALBUQUERQUE-LOS ALAMOS

"Frontiers in Communications," by Karl Honoman, Bell Telephone Labs.; October 15, 1953.

"Information Theory," by B. M. Oliver; November 10, 1953.

ATLANTA

Field Trip to Anniston Tube Plant, General Electric Co., Oxford, Alabama; October 16, 1953.

BALTIMORE

"Microwave Spectroscopy," by L. E. Norton, RCA, David Sarnoff Research Center; October 14, 1953.

"Field Effect Transistor," by Dr. G. C. Dacey, Bell Telephone Labs.; November 11, 1953.

BEAUMONT-PORT ARTHUR

Discussion and Application of Modern Computers, by J. D. Rice, Faculty, Lamar State College of Technology; November 11, 1953.

BINGHAMTON

"Ferrites," by F. F. Sylvester, General Ceramics and Steatite Corp.; October 19, 1953.

Discussion of a New Thirty (30) Watt Amplifier by Sidney Corderman, McIntosh Engineering Laboratory; November 9, 1953.

BUFFALO-NIAGARA

"Color Reproduction and the New Proposed Color Television Standards," by K. R. Wendt, Sylvania Electric Products Inc.; October 21, 1953.

CLEVELAND

"Radiation Interference Problems," by James Hill and J. H. Campbell, General Electric Company; "Certification of Equipment," by R. C. McNabb, General Electric Company; October 20, 1953.

COLUMBUS

"The Practical Applications of Transistors," by R. J. Kircher, Bell Telephone Labs.; October 14, 1953.

DALLAS-FORT WORTH

"Automatic Fabrication of Electronic Components," by Dr. Cledo Brunetti, General Mills, Inc.; November 5, 1953.

Inspection Tour of New Manufacturing Plan and Transistor Plant, Texas Instruments, Inc.; November 18, 1953.

DAYTON

"Your Kitchen May Be Getting Away from You," by W. B. Hall, General Electric Company; November 12, 1953.

DES MOINES-AMES

Presentation by Alfred Crossley Associates of Their Electronic Instrument Exhibit and Demonstration; October 20, 1953.

"Principles of Color Television," by C. H. Hoyler, RCA Labs.; October 28, 1953.

DETROIT

"Detection and Measurement of Radioactivity," by J. R. Niles, Radioactive Products, Inc.; September 18, 1953.

"Radio Astronomy," by D. O. McCoy, Collins Radio Company; October 16, 1953.

ELMIRA-CORNING

"The Physical Process of Secondary Emission," by E. J. Sternglass, Westinghouse Research Labs.; October 19, 1953.

(Continued on page 102A)

SECTION MEETINGS

(Continued from page 100A)

EL PASO

"The Physics of Music and Hearing"—Tape-script by Dr. Koch, Bell Telephone Labs.; October 13, 1953.

EMPORIUM

"Physical Effects of High Intensity Sound Waves in Air," by Dr. Schilling, Pennsylvania State College; October 21, 1953.

EVANSVILLE-OWENSBORO

"Relays for Industry and Defense," by Richard Brumfield, Potter & Brumfield Company; November 11, 1953.

FORT WAYNE

"Magnetic Amplifier Circuit Fundamentals and Applications," by A. E. Schmid, The Magnavox Company; November 5, 1953.

HAMILTON

"Color Reproduction and Proposed NCTSC Standards," by K. R. Wendt, Sylvania Electrical Products, Inc.; October 21, 1953.

HOUSTON

Tour of Police Administration Building; Demonstration of a Lie Detector; and Film on Houston Police Facilities; September 15, 1953.

"The Chemistry and Physics of Transistors," by Dr. G. K. Teal, Texas Instruments Inc.; October 20, 1953.

"Our Expanding Electronic Technology," by J. W. McRae, President, IRE; November 12, 1953.

INYOKERN

Papers presented by NOTS Staff; October 16, 1953.

"Ultra-High Frequency Klystron Power Amplifiers," by C. E. Murdock, Eitel-McCullough, Inc.; November 9, 1953.

LITTLE ROCK

"Measurement of Tube Performance at Ultra High Frequencies," by J. W. Rush, General Electric Company; November 10, 1953.

LONDON

"Ferrites and Their Application," by A. Ainlay, Rogers Majestic Electronics Ltd.; November 2, 1953.

LOS ANGELES

"Color Television," by Roger Dorr, Chromatic Television Lab. Inc.; September 1, 1953.

"Patents, Engineers and the New Law," by H. R. Lubcke, Patent Agent and Consulting Engineer; "Recent Developments in Television Recording," by R. M. Lovell and R. N. Olsen, National Broadcasting Company. Dinner Speaker: "Recent Developments in the Field of Electron Tubes and Devices," by Bernard Walley, RCA; October 6, 1953.

"Communication System of Southern California Edison Company," by K. E. Dueker, Southern California Edison Company; and "Impedance Measurements in the Microwave Frequency Range," by W. R. Hewlett, Hewlett-Packard Company; Dinner Speaker: "Project Durand," by F. A. Cleveland, Lockheed Aircraft Company; November 3, 1953.

LOUISVILLE

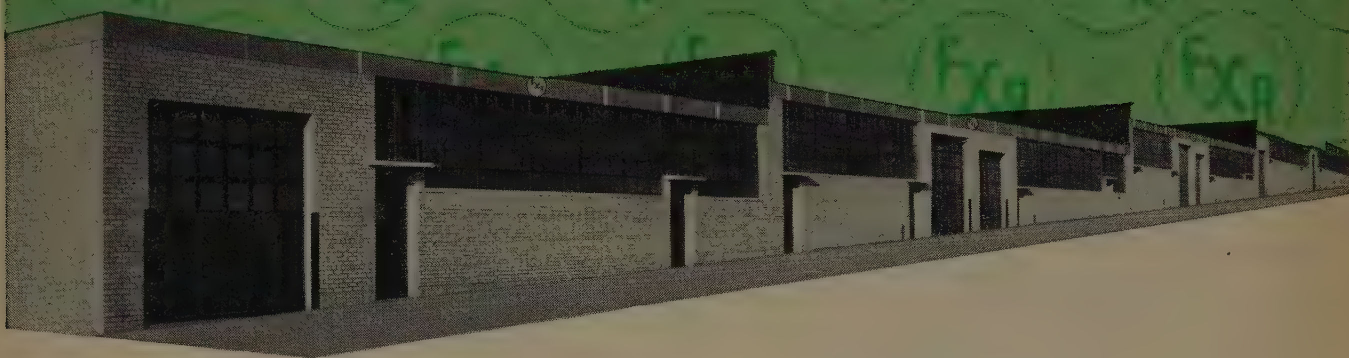
"Television Interference; It's Causes and Cures," by L. G. McCoy, American Radio Relay League; November 13, 1953.

MILWAUKEE

"Western Union's New Telefax," by Raleigh Hoagberg and R. W. Underwood, Western Union Telegraph Company; October 8, 1953.

(Continued on page 104A)

STEP UP PRODUCTION



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SECTION MEETINGS

(Continued from page 102A)

MONTREAL

"Television in Canada," by J. E. Hayes, Canadian Broadcasting Corp.; November 2, 1953.

NEW YORK

"Ferroelectrics and the Dielectric Amplifier," by W. P. Mason, Bell Telephone Labs., Inc.; October 7, 1953.

"Guided Missiles, Weapons Old and New," by D. E. Mullen, General Electric Company; November 4, 1953.

OKLAHOMA CITY

"Transistors," by Harvey McMains, Bell Telephone Company; October 15, 1953.

"Telemetering," by M. V. Kiebert, Ordnance Br. East Coast Aeronautics; November 3, 1953.

OTTAWA

"Air-to-Air Propagation," by Dr. L. H. Doherty, The National Research Council; Dinner Speaker: "Comments on U.R.S.I. Meeting in Ottawa," by J.W. C. Scott, Defence Research Board; October 22 1953.

PHILADELPHIA

"Quality Control," by Dr. E. D. Burdick, University of Pennsylvania; October 21, 1953.

"Design of Experiments," by Dr. J. W. Tukey, Princeton University; October 28, 1953.

"Random Processes in Engineering," by Dr. Mark Kac, Cornell University; November 4, 1953.

"A Method of Time compression or Expansion of Speech," by Dr. W. L. Everitt, Dean of College of Engineering, University of Illinois.

"Noise," by W. R. Bennett, Bell Telephone Labs.; November 11, 1953.

"Information Theory," by Brockway McMillan, Bell Telephone Labs.; November 18, 1953.

PORTLAND

Field trip to Electronics Division of Iron Fireman, Inc.; October 6, 1953.

"Ferroelectric Storage Devices" (Tapescript) by J. R. Anderson, Bell Telephone Labs.; "A Junction Transistor Tetrode for High Frequency Use (Tapescript) by R. L. Wallace, Bell Telephone Labs.; October 22, 1953.

"Koin Television Transmitting Station," by B. R. Paul, Station KOIN and KOIN-TV; Field trip to transmitter site; November 5, 1953.

SCHENECTADY

"Applications of Ultrasonics in Industry," by D. B. Connelly, General Electric Company; October 12, 1953.

"GL-6299-A New Low Noise U.H.F. Amplifier Tube," by G. C. Downing, General Electric Company; November 9, 1953.

ST. LOUIS

"Contemporary Train Communication Systems," by L. E. Verberg; Missouri Pacific Lines; October 15, 1953.

"Instrumentation in Seismology," by Dr. Florence Robertson, St. Louis University; November 12, 1953.

SYRACUSE

"Electrical Engineering in Medicine," by Dr. H. M. Rozendaal, General Electric Research Laboratory; October 15, 1953.

TOLEDO

Films: "Manufacture of High-Fidelity Audio Tape" and "Manufacture of Stem Glassware"; September 10, 1953.

"Radio Telemetry for Aircraft and Guided Missiles," by Prof. M. H. Nichols and Prof. L. L. Rauch, University of Michigan; October 8, 1953.

(Continued on page 146A)

Precision Designed for LOWEST VSWR!

PRD microwave TRANSMISSION LINE components

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TYPE 354-B
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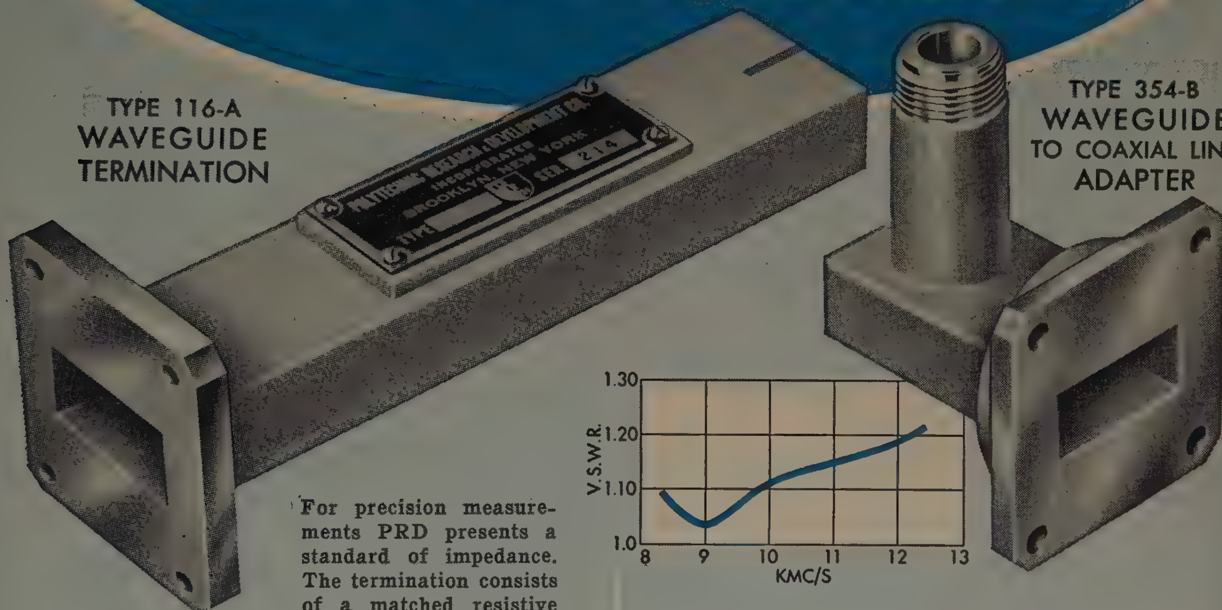

- Frequency Range: 8.2 to 12.4 kmc/s
- Very Low VSWR: Less than 1.015
- Stable Characteristics
- Rugged
- Waveguide Type: RG-52/U
- Flange Type: UG-39/U

For precision measurements PRD presents a standard of impedance. The termination consists of a matched resistive insert terminating a section of RG-52/U waveguide. Each insert is tested to insure that its VSWR is less than 1.01. Dimensions of the waveguide are maintained so that its characteristic impedance is within 0.5 percent of nominal. Flange faces are milled flat and the screw holes are referenced to the center line.

- Wide Frequency Range: 8.2 to 12.4 kmc/s
- Low VSWR: (See curve)
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- Flange Type: UG-39/U
- Coaxial Connector: Mates with UG-21B/U or equivalent

The Type 354-B Adapter is designed for making minimum reflection connections between waveguide and coaxial line. Typical VSWR is shown in the curve. The low VSWR assures least disturbance of the electrical properties of mating components.

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STUDENT BRANCH MEETINGS

UNIVERSITY OF CALIFORNIA, IRE-AIEE BRANCH

General Business Meeting; October 6, 1953.

CALIFORNIA INSTITUTE OF TECHNOLOGY IRE BRANCH

"Microwave Techniques," by Mr. Bob Brunner, Neely Enterprises; November 2, 1953.

CALIFORNIA STATE POLYTECHNIC COLLEGE, IRE BRANCH

"The Opportunities for an Engineer in Sales and Distribution," by E. Tilton, Pacific Wholesale Co.; November 5, 1953.

CLARKSON COLLEGE OF TECHNOLOGY, IRE BRANCH

Films, on the following subjects: Capacitance, Radio Antennas, Micro-wave oscillators and Election of Officers; November 19, 1953.

UNIVERSITY OF CONNECTICUT, IRE-AIEE BRANCH

"Switchgear Mechanism," by Dr. W. M. Leeds, Circuit Breaker Section of Westinghouse; Oct. 15, 1953.

COOPER UNION SCHOOL OF ENGINEERING, IRE-AIEE BRANCH

Introductory Meeting; October 8, 1953.

Films, "The Creation and Behavior of Radio Waves" and "The Fundamentals of the Antenna"; Oct. 22.

Films, on Radio Transmitters and Radar; October 29, 1953.

UNIVERSITY OF DAYTON, IRE-AIEE BRANCH

"Simplified Wire Table Calculations," by Jerome F. Kiener, Student Member; October 13, 1953.

UNIVERSITY OF DENVER, IRE-AIEE BRANCH

General Business Meeting; October 30, 1953.

Film, "Motors in Industry"—General Electric; November 2, 1953.

Film, "Underwater Giant"—Oakonite Company; November 16, 1953.

UNIVERSITY OF DETROIT, IRE-AIEE BRANCH

"Activities of the I.R.E. and A.I.E.E.," by Prof. R. W. Alhquist, Faculty University of Detroit; October 15, 1953.

DREXEL INSTITUTE OF TECHNOLOGY, IRE-AIEE BRANCH

"Life Begins at 80," by W. B. Morton, Power and Light Co.; October 15, 1953.

UNIVERSITY OF FLORIDA, IRE-AIEE BRANCH

"Engineers Contributions to Florida," by Mr. Ralph Turlington, State Representative, Alachua, County; September 29, 1953.

"The Engineering Challenge of the 20th Century," by W. F. Fagen, Professor, University of Florida; October 13, 1953.

"Magic Memory," by Professor Wiggins, Faculty, University of Florida; October 27, 1953.

GEORGE WASHINGTON UNIVERSITY, IRE BRANCH

"Project Tinkertoy," by Mr. Herbert Rosen, National Bureau of Standards and Film of the same title; November 4, 1953.

IOWA STATE COLLEGE, IRE-AIEE BRANCH

Film on Impregnated Paper Insulated Cables, Okonite Cable Co.; October 21, 1953.

(Continued on page 109A)

STUDENT BRANCH

MEETINGS

(Continued from page 106A)

STATE UNIVERSITY OF IOWA, IRE BRANCH

Films, "Television and How It Works" and "Stepping Forward With Television"; October 30, 1953.

"Long Distance Toll Dialing," by Mr. Paul Hintz, North Western Bell Telephone Co.; November 4, 1953.

"Major Advances in the Steel Industry During the Last Decade," by S. T. Jazwinski, U. S. Steel Inc." November 11, 1953.

KANSAS STATE COLLEGE, IRE BRANCH

Election of Officers; October 1, 1953.

UNIVERSITY OF MAINE, IRE BRANCH

"Summer Work at Western Electric Company," by Robert C. Goodall and Robert J. Willett, both Student Members IRE and Election of Officers; October 22, 1953.

"Synchro-Machines," by L. King, Student and "Summer Work with Power Companies," by Guy Twombly and Allen Bingham, Students, University of Maine. Films, "RF Induction Heating" and "Unit Substations"—Westinghouse; November 19, 1953.

UNIVERSITY OF MARYLAND, IRE-AIEE BRANCH

Business Meeting, Appointment of Committee Chairmen; October 7, 1953.

UNIVERSITY OF MASSACHUSETTS, IRE-AIEE BRANCH

"AC Network Analyzers," by S. H. Lull, Western Mass. Electric; October 14, 1953.

UNIVERSITY OF MICHIGAN, IRE-AIEE BRANCH

"Developments in the Power Field," by D. L. Chesnut, General Electric Co.; October 28, 1953.

"The Principles of Color Television," by C. W. Hoyler, RCA, Princeton; November 18, 1953.

MICHIGAN COLLEGE OF MINING AND TECHNOLOGY, IRE-AIEE BRANCH

Business Meeting; October 20, 1953.

UNIVERSITY OF MINNESOTA, IRE-AIEE BRANCH

"Secondary Emission Project," by Dr. W. G. Shepherd, Faculty, University of Minnesota; November 13, 1953.

MISSOURI SCHOOL OF MINES AND METALLURGY, IRE-AIEE BRANCH

Informal talk with slides and Movies on outdoor generating stations, by R. F. Danner, Oklahoma Gas and Electric; October 22, 1953.

UNIVERSITY OF NEBRASKA, IRE-AIEE BRANCH

General Meeting; September 23, 1953.

Film, "Atomic Energy" and General Meeting; October 7, 1953.

UNIVERSITY OF NEW MEXICO, IRE-AIEE BRANCH

"Quartz Crystals," by J. L. Ellis, Faculty, University of New Mexico; October 7, 1953.

"New Type Electric Pressure Transducers," by James C. Clark, Lovelace Research Foundation; November 16, 1953.

NEW MEXICO COLLEGE OF AGRICULTURE AND MECHANIC ARTS, IRE-AIEE BRANCH

"What AIEE-IRE mean to EE Students," by Russell L. Reese and Dr. C. D. Crosno, both Faculty, N. Mexico State College; October 22, 1953.

"Rocket Instrumentation," by Gilbert Moore Physical Science Laboratory; November 12, 1953.

(Continued on page 110A)

STUDENT BRANCH MEETINGS

(Continued from page 109A)

COLLEGE OF CITY OF NEW YORK, IRE BRANCH

"Analog Computers," by Abraham Karen, Reeves Instrument Corp; October 22, 1953.

"Pipe Type Cable," by Robert W. Gillette, Consolidated Edison; October 29, 1953.

"Transistors," by Robert H. Vogelman, Rome Air Development Center; November 5, 1953.

NORTH CAROLINA STATE COLLEGE, IRE BRANCH

"Operation Granpa"—Graphical and Numerical Photoelectric Analyser, by Dr. V. S. Carson, Faculty, N. C. State College; October 27, 1953.

"Pilotless Aircraft," by E. A. Brummer, Louisiana State University and F. B. Smith, University of South Carolina and "The Honor System at North Carolina State College," by Dr. Beaver, Faculty, N.C.S.C.; November 17, 1953.

UNIVERSITY OF NORTH DAKOTA, IRE-AIEE BRANCH

"Opportunities in the Training Program at Westinghouse," by Mr. Scott, Westinghouse Corp; November 4, 1953.

OHIO STATE UNIVERSITY, IRE-AIEE BRANCH

"Organizational Meeting; October 8, 1953.

Film, "F-90 Progress Report," by Mr. Detweiler; October 29, 1953.

"Mountaineering" (illustrated with slides) by E. Milton Boone, Director of Tube Lab. at Ohio State University; November 13, 1953.

OKLAHOMA AGRICULTURAL & MECHANICAL COLLEGE IRE-AIEE BRANCH

"Transistor Theory, Devices, and Circuits," by Harvey J. McMains, Southwestern Bell Telephone; November 2, 1953.

UNIVERSITY OF PITTSBURGH, IRE BRANCH

"Color Television Techniques and Development," by Howard Jones, Westinghouse Corp.; October 22, 1953.

RUTGERS UNIVERSITY, IRE-AIEE BRANCH

Field Trip through ASCOP and RCA Laboratories conducted by J. K. Delano, Exec. Vice President of ASCOP and R. F. Snyder of RCA; October 16, 1953.

"Voltage Coefficients of Composition Resistors," by Louis Rosenthal, Faculty Rutgers University; October 29, 1953.

ST. LOUIS UNIVERSITY, IRE BRANCH

Talk and Film on IBM Machines by Mr. Robert Brown, I.B.M. and General Meeting; October 21, 1953.

SAN DIEGO STATE COLLEGE, IRE BRANCH

"Analog Computers," by Solomon Bialek, Student, San Diego State College; October 13, 1953.

UNIVERSITY OF SOUTHERN CALIFORNIA, IRE-AIEE BRANCH

"Microwave Facilities with Field Trip Combination," by Mr. Miller, Senior Engineer; October 22.

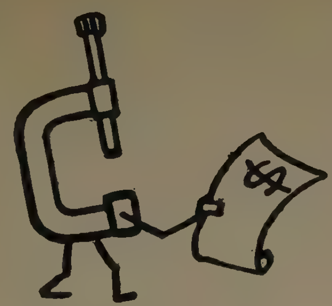
"The Engineer in Industry," by S. M. Johns and E. W. Morris, both of Westinghouse Electric Co.; November 18, 1953.

STANFORD UNIVERSITY, IRE-AIEE BRANCH

Film, "Underground Transmission Lines," and General Meeting; November 4, 1953.

Tour-Microwave Lab and High Energy Physics by Dr. Charles Siskind, Electronics Research Staff; November 12, 1953.

(Continued on page 112A)



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STUDENT BRANCH MEETINGS

(Continued from page 110A)

University of Syracuse, IRE-AIEE Branch

Organizational Meeting; October 21, 1953.

"Color Television," by Mr. Abrahams, General Electric; November 11, 1953.

Texas Technological College, IRE-AIEE Branch

Presentation of Scholarships to Students, H. L. Allen, J. T. Geer, R. L. Beale; October 19, 1953.

"Automations and Servo-mechanism," by H.A. Spuhler, Faculty Texas Tech.; November 2, 1953.

University of Toronto, IRE-AIEE Branch

"Substations," by Mr. D. A. Mitchell, Ontario Hydro Electrid Power Commission; October 30, 1953.

Tufts College, IRE-AIEE Branch

Business Meeting; October 21, 1953.

Tulane University, IRE-AIEE Branch

"Electronics in the Search for Oil," by J. V. Boone, Student and General Meeting; September 29, 1953.

"Resonant Circuits: Their Effects & Applications," by C. H. Robards, Student; October 20, 1953.

Utah State Agricultural College, IRE Branch

"What Industry Expects of Engineers," by Melvin J. Greaves, Faculty Utah State Agriculture College; October 29.

Virginia Polytechnic Institute, IRE-AIEE Branch

"Electronics Demonstration and Lecture," by Mr. Smith and Mr. Caldwell both from Bevins & Caldwell; October 20.

Sound Strip on Westhinghouse MU Radar; October 27, 1953.

"Instrumentation in high speed test aircraft," by Mr. Youngblood and Mr. A. C. Taylor representatives of the National Advisory Committee for Aeronautics; November 3, 1953.

"The I-50 G.E. Watt-hour Meter," by Mr. Edward Howell, General Electric Co.; November 10, 1953.

Business Meeting; November 17, 1953.

Wayne University, IRE-AIEE Branch

"Applications of Electronic & Magnetic Amplifiers as Control Devices," by Mr. James Walker, Eng'g. Research Staff, Wayne University; October 22, 1953.

University of Wisconsin, IRE-AIEE Branch

"What to Expect on Your First Engineering Job," by R. LaPlante, M.S., Faculty, Univ. of Wisconsin; October 7, 1953.

"Psychology and the Engineer," by L. E. Drake, Faculty, University of Wisconsin; November 5, 1953.

University of Wyoming, IRE-AIEE Branch

General Meeting; October 13, 1953.

Film, "Piercing the Unknown," I.B.M. and General Meeting; October 27, 1953.

General Meeting; November 10, 1953.

Yale University, IRE-AIEE Branch

"Position of Engineers in Activities Outside the Engineering Field," by F. T. McNamara, Faculty, Yale University; October 15, 1953.

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MEMBERSHIP

The following transfers and admissions were approved to be effective as of January 1, 1954:

Transfer to Senior Member

Banta, H. E., 37 Outer Dr., Oak Ridge, Tenn.
Benner, R. H., II, Apt. 227-A, Haddon Hills Apartments, Haddonfield, N. J.
Chen, T. C., 418 Steel Rd., Havertown, Pa.
Church, T. S., 3325—49 Loop, Sandia Base, Albuquerque, N. Mex.
Cole, W. P., Box 356, R.F.D. 2, Quakertown, Pa.
Elliott, R. S., Microwave Laboratory, Hughes Aircraft, Culver City, Calif.
Fields, T., 8021 S. Bennett Ave., Chicago 17, Ill.
Fuller, W. D., 2608 Larry Dr., Garland, Tex.
Gilmore, J. P., 228C Hillcrest Ave., Collingswood, N. J.
Greer, W. R., Jr., 901 Potomac Ave., Alexandria, Va.
Harman, W. W., Electronics Researcch Laboratory, Stanford University, Stanford, Calif.
Hudson, P. K., Electrical Engineering Department, University of Illinois, Urbana, Ill.
Kelley, E. K., 336 E. Fourth St., Loveland, Colo.
Kenney, T. C., KDKA, Grant Bldg., Pittsburgh 19, Pa.
King, P. B., Jr., Aircraft Radio Corp., Boonton, N. J.
Lader, L. J., 6388 West 77 St., Los Angeles 45, Calif.
Martin, D. W., The Baldwin Co., 1801 Gilbert, Cincinnati 2, Ohio
Mathews, R. H. G., Burton Browne Advertising, 619 N. Michigan Ave., Chicago, Ill.
Mulligan, J. H., Jr., 483 Colonial Rd., Ridgewood, N. J.
Rosen, L., 52 Lake Rd., Framingham, Mass.
Saad, T. S., 105 Keith St., West Roxbury 32, Mass.
Saunders, G. H., 92 Ninth St., W., Huntsville, Ala.
Schlicke, H. M., 7469 N. Lombardy Rd., Milwaukee 11, Wis.
Sinclair, R. O., Jr., Bell Telephone Laboratories, Whippany, N. J.
Sittner, W. R., Bell Telephone Laboratories, 555 Union Blvd., Allentown, Pa.
Thomas, R. K., 724 Stevenson La., Towson 4, Md.
Wallace, R. J., 9600 St. Lawrence Blvd., Montreal 14, Que., Canada
Woodcock, E. L., 14 Trumpet La., Levittown, L. I., N. Y.

Admission to Senior Member

Chappuis, C. K., 3394 Audubon Rd., Montgomery Ala.
Cothron, W. C., Graybar Electric Co., Inc., 420 Lexington Ave., New York 17, N. Y.
Erickson, P. W., 81 Brettwood Rd., Belmont 78, Mass.
Gibson, O. B., 195 Broadway, American Telephone & Telegraph Co., New York 7, N. Y.
Glass, R. E., 3411—51 Loop, Sandia Base, Albuquerque, N. Mex.
Gray, C. S., c/o Sperry Farragut Corp., Bristol, Tenn.
Kupfer, R. C., 2316 N. Catalina St., Hollywood 27, Calif.
Lannan, P. E., 2915 Detroit Ave., Cleveland 13, Ohio
Martin, R. L., 1411 Alston St., Marysville, Kans.
Max, A. J., 1801 Ridgecrest Dr., S.E., Albuquerque, N. Mex.
Miller, K. M., Lear, Inc., 11916 W. Pico Blvd., Los Angeles, Calif.
Morita, K., Tokyo Institute of Technology, Ookayama Meguro-ku, Tokyo, Japan

(Continued on page 116A)

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(Continued from page 114A)

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(Continued on page 118A)

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- Accuracy ±.5 DB, no correction charts necessary.
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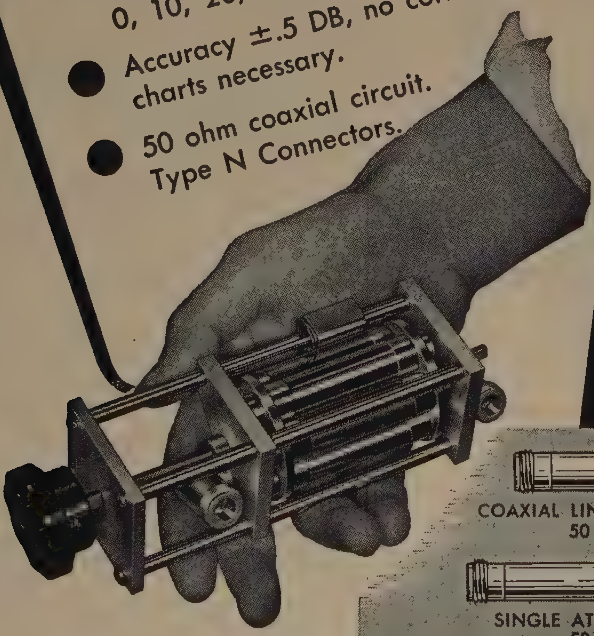

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50 ohms

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VSWR ± 1.2 to 3000 mc.
One watt c.w. power dissipation

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(Continued from page 118A)

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Angele, W., 1903 Scenic Dr., Huntsville, Ala.
Arasim, J., Jr., R.F.D. 7, Jackson, Mich.
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Bailey, H., 2430 Pennsylvania Ave., N.W., Washington 7, D. C.
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Bushnell, R. R., 133 Brookfield Rd., Riverside 15, R. I.
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Corwin, G., 11 Bellflower St., Lexington 73, Mass.

(Continued on page 121A)

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(Continued on page 124A)

NEW! FOR PRINTED

COMPLETE LINE

1 FOR AUTOMATION: EXCLUSIVE NEW Self-Supporting Snap-in Bracket Mounting. (See Type YGC-B45.)

2 NEW Twist-ear Mounting. (See Types XP45 and UPM45.)

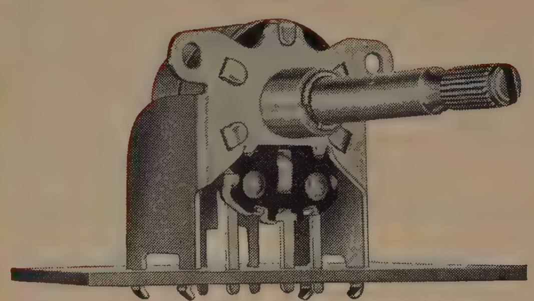
3 PLUG-IN BLADE-TYPE TERMINALS for vertical or horizontal mounting of control to printed circuit panel. (See all photos.)

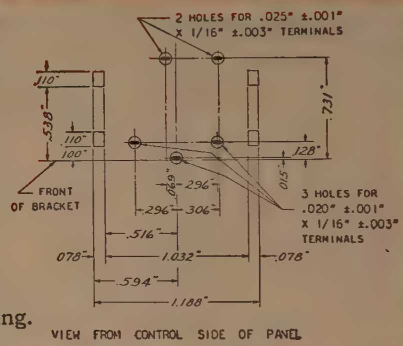
4 Threaded Bushing Mounting. (See Types XGC-45, GC-U45 and *miniaturized* U70.)

Consultation without obligation available on variable resistors for your printed circuit applications. Write today.

VERTICALLY MOUNTED to Printed Circuit Panel. Shaft above panel. (Types YGC-B45, XP45 and XGC-45.)

- NO shaft protection needed during soldering.
- PARALLEL terminals permit *small* round connecting holes instead of *large* elongated slots necessary for fan shaped terminals.
- Terminals available in 7/8″ or 1-1/32″ lengths from control's center.





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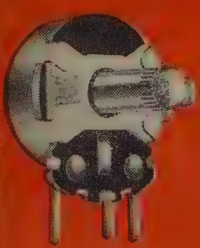
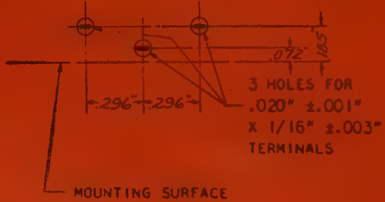
Type YGC-B45 FOR AUTOMATION: *EXCLUSIVE NEW Self-Supporting Snap-in Bracket*

- Snaps instantly into place.
- Stays firmly put during soldering. Solder permanently anchors control to circuit panel.
- Terminal connections cannot loosen; bracket prevents mounting or operating strain on control or switch terminals.
- No mounting hardware, no separate supporting panel needed.
- No strain on printed circuit panel. Anchor tabs attach bracket to cabinet.
- Adequate clearance for circuit paths provided by ample spacing between terminals and by design of mounting lugs on bracket.

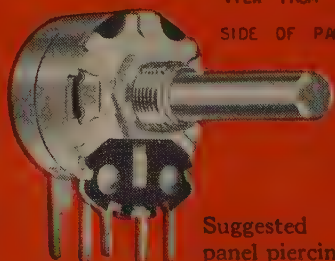


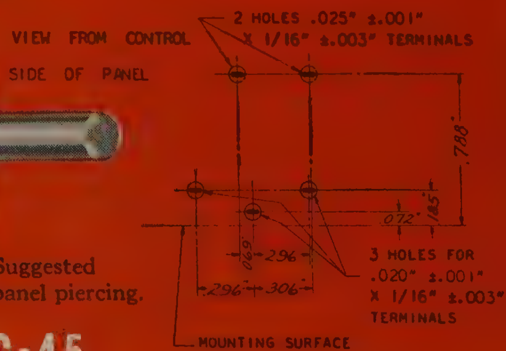


Suggested panel piercing.

Type XP45

For TV preset control applications using a mounting chassis to support printed circuit panel. Twisting 2 ears holds control rigidly to mounting chassis. Available in finger adjusted shaft lengths of 1/2″, 5/8″, 11/16″, 7/8″ and 1″ from control's mounting surface. Also





Suggested panel piercing.

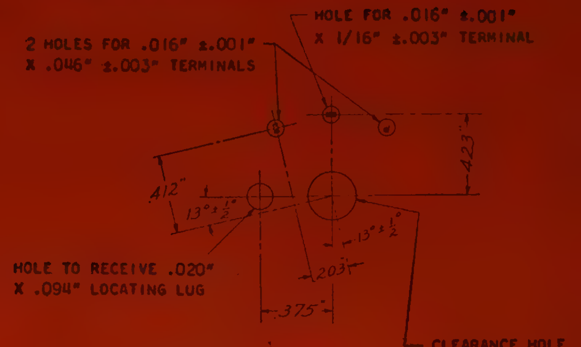
Type XGC-45

For applications using a mounting chassis to support printed circuit panel. Threaded bushing mounting.

CIRCUITS OF VARIABLE RESISTORS

Type U70
(Miniaturized)

Threaded bushing mounting. Terminals extend perpendicularly 5/32″ from control's mounting surface.



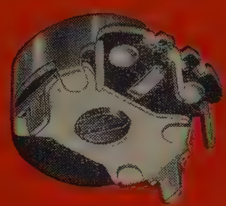
Suggested panel piercing.

HORIZONTALLY MOUNTED

to Printed Circuit Panel. Shaft extends through panel. (Types U70, GC-U45 and UPM45.)

Type GC-U45

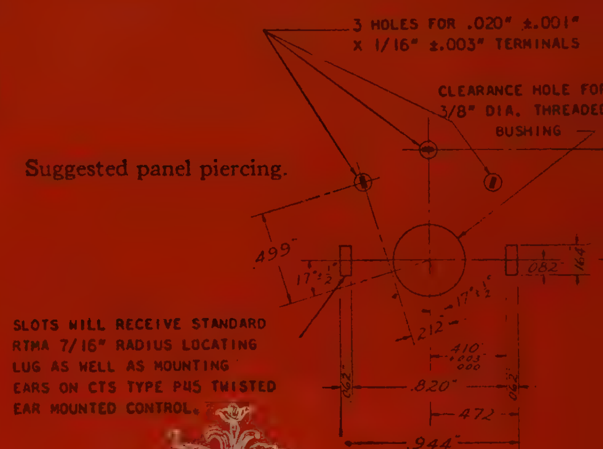
Threaded bushing mounting. Terminals extend perpendicularly 7/32″ from control's mounting surface. Available with or without associated switches.



Type UPM45

For TV preset control applications. Recessed screw-driver slotted shaft remains solder-free during panel dipping. Control may be held rigidly to panel before soldering by twisting 2 ears. If ears are left straight, the solder will permanently anchor control to circuit panel. Terminals extend perpendicularly 7/32″ from control's mounting surface.

Suggested panel piercing.



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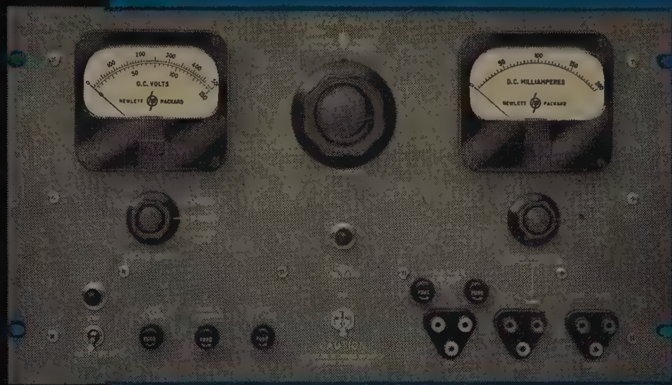
- **INTERNAL IMPEDANCE 0.1 OHM, 25 μH**
- **HUM LESS THAN 500 μV**
- **SEALED TRANSFORMERS, CHOKES, CONDENSERS**



-hp- 712B Power Supply

Model 712B Power Supply is deliberately designed to give you the finest performance obtainable plus broadest usefulness and the lowest price consistent with quality. It offers high regulation, low internal impedance, low ripple, and the exceptionally fast transient response of 0.1 milliseconds. It also provides four outputs for maximum applicability, and less than 50 millivolts change (no-load to full-load) at any regulated output voltage. The instrument has a 0 to 500 volt, 200 ma regulated supply, and a fixed 300 volt tap making available a 50 ma, 300 to 800 volt variable supply for klystron operation. Continuously variable bias voltages, separate voltage and current meters, and generous overload protection are provided.

Model 712B will meet the most exacting requirements of heavy duty laboratory or production work. It is particularly useful in powering temporary setups, oscillators, small transmitters, complex systems and certain types of klystrons.

To insure long, trouble-free operation, Model 712B has sealed transformers and chokes, oil-filled filter condensers, and is fully fused. Only high quality components are used, and no electrolytic condensers are employed.

OTHER *-hp-* POWER SUPPLIES

-hp- also offers two other high stability, high regulation DC or AC power supplies. *-hp-* 710A provides output continuously variable 180 to 360 volts with regulation of 1% and hum less than 0.005 volts. *-hp-* 710B is identical except has voltage range of 100 to 360 volts. *-hp-* 710A, $85.00; *-hp-* 710B, $100.00 f.o.b. factory.

For complete information, see your *-hp-* field representative or write direct

HEWLETT-PACKARD COMPANY
2948D Page Mill Road • Palo Alto, California, U. S. A.

SPECIFICATIONS

OUTPUT VOLTAGES:
DC Regulated High Voltage: 0 to +500 volts (without switching), 200 ma. max. load.
DC Regulated Fixed Bias: —300 volts, 50 ma. max. load.
DC Variable Bias: 0 to —150 volts, 5 ma. max. load.
AC Unregulated: 6.3 volts CT, 10 amps max. load.

REGULATION:
(for line voltage 115 volts ± 10%)
DC Regulated High Voltage: Less than 50 millivolts change no-load to full-load at any output voltage.
DC Regulated Fixed Bias: Less than 50 millivolts change no-load to full-load.
DC Variable Bias: Regulated against line voltage changes. Internal impedance 0 to 10,000 ohms depending on bias control setting.

RIPPLE: Less than 500 microvolts.

INTERNAL IMPEDANCE:
DC Regulated High Voltage: (For frequencies above 20 cps.)
Full-load: 0.1 ohm in series with 25 μH max.
No-load: 1 ohm in series with 50 μH max.

RECOVERY TIME: Upon application of full-load: 0.1 millisecond max.
Upon decrease from full-load to:
(a) 0 ma. —0.5 millisecond max.
(b) 25 ma. —0.1 millisecond max.
Maximum transient voltage —1 volt.

METERING: Current Meter: 0 to 200 ma. (high voltage only).
Voltmeter: Three ranges, 0 to +500 volts, 0 to +150 volts and 0 to —150 volts. Panel switch connects meter to DC regulated high voltage or DC variable bias and selects range.

TERMINALS: Either positive or negative DC regulated high voltage terminal may be grounded. Positive terminals of both bias supplies and negative terminal of DC regulated high voltage are common.

OVERLOAD PROTECTION: AC line, DC regulated high voltage, DC regulated fixed bias and filament supply are separately fused. DC regulated high voltage drops to zero if bias fuse blows.

POWER SUPPLY: 115 volts ± 10%, 50 to 1000 cps.

CABINET: Rack Mount. $10\frac{1}{2}''$ high x $19''$ wide x $14\frac{1}{8}''$ deep. Detachable End Frames with handles for bench use, $5.00 pair. (Specify *-hp-* 17 End Frames.)

WEIGHT: 62 lbs. net, shipping weight 100 lbs.

PRICE: $350.00 f.o.b. factory.

Data subject to change without notice.

hp INSTRUMENTS | COMPLETE COVERAGE

(Continued from page 124A)

Peck, N. D., 17 Jamison Pl., Newburgh, N. Y.
Penland, C. L., 583 Ukiah Way, Upland, Calif.
Phalen, F. W., 1960 Edgewood Rd., Towson 4, Md.
Phillips, A. H., 1921 S. Griffith Ave., Owensboro, Ky.
Politzi, V. P., 1553—77 St., Brooklyn 28, N. Y.
Popkiewicz, F., 7008 Colonial, Dearborn 6, Mich.
Price, H. K., 381 W. Broad St., Telford, Pa.
Randolph, G. C., 39 West 75 St., New York 23, N. Y.
Reach, R. W., Jr., Raytheon Manufacturing Co., Computer Department, Laboratory 30, Waltham, Mass.
Ritter, R. E., 514 Elton St., Brooklyn, N. Y.
Rivera, C. R., 317 Springfield Rd., East Syracuse, N. Y.
Rohlinger, D. J., Wright Air Development Center, Area B, Box 8905, Wright-Patterson AFB, Ohio
Rose, W. A., 2161 Suncrest Dr., Cuyahoga Falls, Ohio
Rowland, W. H., Buxton Hill, Williamstown, Mass.
Ryan, L. E., American Embassy, APO 928, c/o Postmaster, San Francisco, Calif.
Santamaria, S., 726 Eldridge Ave., West Collingswood, N. J.
Scarborough, F. S., Southworth St., Williamstown, Mass.
Scheetz, H. A., 1720 W. Water St., Elmira, N. Y.
Scheil, R. H., 1805 Spruce, Kansas City, Mo.
Schweber, S. C., Box 669, Mineola, L. I., N. Y.
Scott, C. H., Jr., 144-A Wallworth Pk., Haddonfield, N. J.
Scott, J. E., 98-34—63 Dr., Apt. 6-F, Forest Hills 74, L. I., N. Y.
Seixas, A. D., Box 2180, Houston 1, Tex.
Sinclaire, L. W., 21 Spinning Rd., Dayton 3, Ohio
Sivernell, R. B., 1900 Queen St., Fort Worth, Tex.
Small, R. E., 4848 Fauntleroy Ave., Seattle 6, Wash.
Smith, J. F., Naval Ordnance Laboratory, White Oak, Silver Spring, Md.
Smith, J. H., Jr., 1713 W. Erie Ave., Philadelphia 40, Pa.
Smith, L. A., 121 Lower Valley Pike, Springfield, Ohio
Smith, R. L., 31 Magoun Ave., Medford 55, Mass.
Smith, W. D., 159 Stinson St., Hamilton, Ont., Canada
Soto, L. G., 2520 W. Holden Pl., Denver 4, Colo.
Spillane, L. W., 4803 Edgefield Rd., Bethesda, Md.
Srinivasan, K., Principal, Srilax Radio College, 22 W. Avani Moola St., Madurai, S. India
Stevens, R. E., 1408 Ridge Rd., Munster, Ind.
Sticht, R. J., 1987 Elaine Ave., Pomona, Calif.
Strader, F. E., 202 Burke Ave., Towson 4, Md.
Stratton, B. L., 97 Sherwood Ave., Toronto 12, Ont., Canada
Tackett, H. A., 1548 Nash St., Garland, Tex.
Tantzen, R. G., 805 Dewey La., Alamogordo, N. Mex.
Thompson, J. A., 45½ W. Broad St., Hopewell, N. J.
Thompson, W. S., 420 S.W. Glenview Ave., Beaverton, Ore.
Thornwall, J. C., Box 44, The Plains, Va.
Troll, W. C., 2462 Delaware Ave., Buffalo 16, N. Y.
Van Valkenburg, H. E., Sperry Products, Inc., Danbury, Conn.
Van Vliet, W. G., 11 Bedford Ave., Apt. N-1, Norwalk, Conn.
Venkatarangan, A., 5 Radharkrishnan St., Madras 17, India
Volf, L. F., Box 424, Moncks Corner, S. C.
Walkup, L. A., 4904—14 Ave., S., Minneapolis 17, Minn.
Wandrey, H. B., 2903 North 19 St., Milwaukee, Wis.
Weingarten, I. R., 81 Green Ridge Dr., E., Elmira, N. Y.

(Continued on page 128A)

MEMBERSHIP

(Continued from page 126A)

Wenzel, G. E., Ápartado 3421, Caracas, Venezuela
Willes, R. L., 5712 Farragut Rd., Brooklyn 34, N. Y.
Williams, O. L., Bell Telephone Laboratories, Murray Hill, N. J.
Williams, R. G., "E" Co., 24 SBC 1 Tr. Bt. MCS, Camp Barrett, Quantico, Va.
Wolf, A. B., 23 Phyllis Rd., West Orange, N. J.
Wong, J. B., 1127 S. Charles St., Baltimore 30, Md.
Wray, P. G., 8216 N. Ozanam Ave., Niles, Chicago 31, Ill.
Wrege, L. A., 1630 North 24 St., Milwaukee 5, Wis.
Wright, D. J., 151 Horsham Ave., Willowdale, Ont., Canada
Zinn, L., 3519—215 Pl., Bayside, L. I., N. Y.
Zisk, S. H., 2657 Woodley Rd., Washington, D. C.

Industrial Engineering Notes

(Continued from page 90A)

"Development and Application of Automatic Assembly Techniques for Miniaturized Electronic Equipment," PB 110783, microfilm, $3.75; photostat, $11.25.

"Electromagnetic Resonant Behavior of a Confocal Spheroid Cavity System in the Microwave Region," PB 110594, microfilm, $1.25; photostat, $1.25.

"Electromagnetic Scattering from Two Parallel Conducting Circular Cylinders," PB 110832, microfilm, $4.25; photostat, $12.50.

"Electron Density Distribution in a High Frequency Discharge in the Presence of Plasma Resonance," PB 110596, microfilm, $1.25; photostat, $1.25.

"Error Inherent in the Radar Measurement of Rainfall at Attenuating Wavelength," PB 110875, microfilm, $2.25; photostat, $5.

"Hot-Cathode Arcs in Cesium Vapor," PB 1105, microfilm, $1.75; photostat, $2.50.

"Magneto-Hydrodynamic Waves Generated in an Ionized Gas in a Toroidal Tube Having an Annular d-c Magnetic Field," PB 110824, microfilm, $1.75; photostat, $2.50.

"Microfilm Determination of the Probability of Collision for Slow Electronics in Gases," PB 110597, microfilm, $1.25; photostat, $1.25.

(Continued on page 148A)

ZOPHAR

---WAXES
---COMPOUNDS

Zophar Waxes, resins and compounds to impregnate, dip, seal, embed, or pot electronic and electrical equipment or components of all types; radio, television, etc. Cold flows from 100°F. to 285°F. Special waxes non-cracking at —76°F. Compounds meeting Government specifications plain or fungus resistant. Let us help you with your engineering problems.

108 YEARS

ZOPHAR MILLS, INC.
112-130 26th Street,
Brooklyn 32, N. Y.

SOLID DELAY LINES STOP TIME

Suitable for video integration, computers, time markers, moving target indication, etc. LFE Solid Delay Lines offer important advantages in obtaining precise delay intervals for pulse or modulated signals: Wide ranges of delay, low attenuation, low spurious response, wide bandwidth, smooth pass band, wide temperature range, minimum size and weight, and rugged construction.

For complete information, write: Specialties Div.,

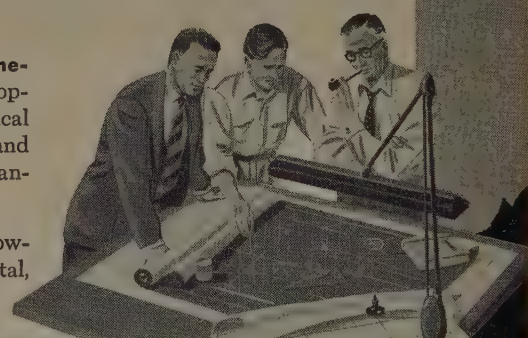
LABORATORY for ELECTRONICS, INC.
75-4 PITTS ST., BOSTON 14, MASS.

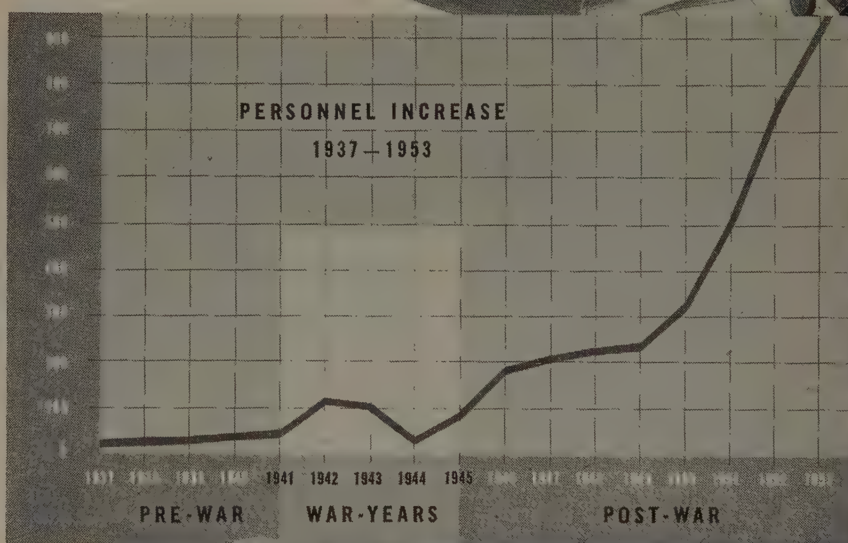
There must be a reason...

SINCE 1937, LIBRASCOPE, INC. of Glendale, California, has been offering careers of satisfaction to engineers. There are four major reasons why engineering personnel choose LIBRASCOPE. Foremost is the opportunity to participate in new and ever-changing problems. At LIBRASCOPE you can vary your experience and background and develop your career more quickly in the proper direction. Job security, good pay and full benefits are important reasons too, and, as the chart shows, greatest growth at LIBRASCOPE has been *since* the war-boom, pointing to a sound industrial future for the Company in the analog-digital computer and control instrumentation field.

Engineers — Physicists — Mathematicians for functional development and design of mechanical and/or electrical computers and for systems evaluation and analysis.

Electronic Engineers in the following: computers, analog or digital, magnetics, servos, packaging.





Computers and Controls

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A SUBSIDIARY OF GENERAL PRECISION EQUIPMENT CORPORATION

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Director of Personnel
1607 Flower Street
Glendale, Calif.

SECTION MEETINGS

(Continued from page 104A)

Tulsa

"Electronic and Instrument Transformers," by John Wardell, Thermador Electrical Manufacturing Company; October 22, 1953.

Twin Cities

Inspection trip of Bell System Radio Relay Terminal. Speaker: R. Johnson, American Telephone and Telegraph; October 27, 1953.

Vancouver

Field trip to Royal Canadian Navy Transmitting Station at Matsqui, B. C.; October 19, 1953.

Washington

"The Ferrite Microwave Magnetometer," by J. P. Allen, U. S. Naval Research Lab.; October 12, 1953.

"The Application of Transistors to Oscillator Circuits," by Dr. William Liben, Johns Hopkins University; November 9, 1953.

Williamsport

"Transistor Circuits and Television Applications," by G. C. Sziklai, R.C.A.; September 23, 1953.

"Transistor Testing Methods," by Prof. R. L. Riddle, Faculty, Pennsylvania State College; October 14, 1953.

SUBSECTIONS

Huntsville

Tour of General Electric Tube Plant, Anniston, Alabama; October 18, 1953.

Lancaster

"The Weatherman's Electronics," by Harold McBirney, U. S. Weather Bureau; November 11, 1953.

Mid-Hudson

"Antennas," by Samuel Schlussel, Channel-master Corp.; October 22, 1953.

Northern New Jersey

"Compatible Color Television and its Relationship to the Broadcaster," by Dr. George Brown, R.C.A.; November 11, 1953.

Orange Belt

"Our Atomic Age," by Dr. N. E. Bradbury, Los Alamos Scientific Laboratory; October 14, 1953.

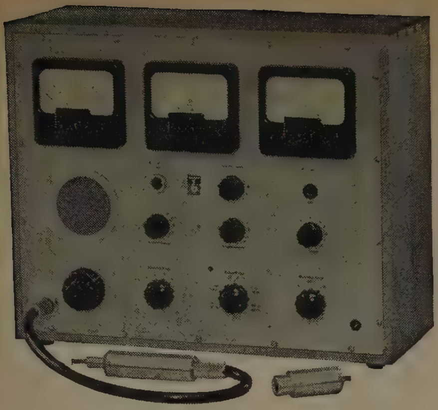
Palo Alto

"The Farnsworth Story," by Donald Lippincott, Patent Attorney; Remarks by Ralph Heintz, Consulting Engineer; October 28, 1953.

U.S.A.F.I.T.

"Magnetic Amplifiers," by Dr. Hoh, WADC, Wright-Patterson AFB; October 1, 1953.

"Use and Limitations of the Digital Computers," by Maj. L. M. Butsch, WADC, Wright-Patterson AFB; November 12, 1953.



MEASURE HIGH-FREQUENCY VOLTAGES

with the BRUEL & KJAER Heterodyne Voltmeter

This selective vacuum tube voltmeter is particularly useful in radio, radar and television circuit measurements, signal generator control, and monitoring of coaxial carrier frequency systems. It is designed for the measurement of high-frequency voltages and has very high sensitivity for measuring extremely small R. F. voltages.

All measurements are made through a test probe. The input voltage is indicated on one meter, and the degree of amplitude modulation of the signal on a second meter. Normal sensitivity is in the microvolt and millivolt range; however, by using an external attenuator this range can be extended to a maximum of 10 volts.

For specifications on the Model BL-2002 Heterodyne Voltmeter and information on the complete line of Bruel & Kjaer Instruments, write Brush Electronics Company, Dept. F-1, 3405 Perkins Avenue, Cleveland 14, Ohio. Outside U. S. A. and Canada, address Bruel & Kjaer, Naerum, Denmark.

ACOUSTIC AND TEST INSTRUMENTS

Bruel & Kjaer instruments, world famous for their precision and workmanship, are distributed exclusively in the United States and Canada by Brush Electronics Company.

- **BL-1012** Beat Frequency Oscillator
- **BL-1502** Deviation Test Bridge
- **BL-1604** Integration Network for Vibration Pickup BL-4304
- **BL-4304** Vibration Pickup
- **BL-2105** Frequency Analyzer
- **BL-2109** Audio Frequency Spectrometer
- **BL-2304** Level Recorder
- **BL-2423** Megohmmeter and D. C. Voltmeter
- **BL-3423** Megohmmeter High Tension Accessory
- **BL-4002** Standing Wave Apparatus
- **BL-4111** Condenser Microphone
- **BL-4120** Microphone Calibration Apparatus and Accessory
- **BL-4708** Automatic Frequency Response Tracer

BRUSH ELECTRONICS COMPANY

formerly The Brush Development Company. Brush Electronics Company is an operating unit of Clevite Corporation.

BRUSH ELECTRONICS

SENSITIVE

D' Arsonval

METER-RELAY

Jeweled Moving Coil Armature

0.2 Microamperes
(0/20 scale range)

0.05 Millivolts
(0/5 scale range)

A.C. D.C.
(voltage - current)

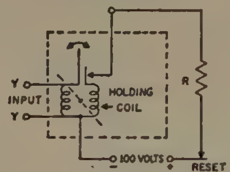
Thermocouples
(R.F. or temperature)

Adjustable
(90° scale arc)

Model 451-C, (4½ inch) double contact, 0/10 DC Millivolts, as used in Vacuum Gauge made by Hastings Instrument Co., Inc., Hampton, Va., used to maintain pressure in a vacuum system.

The contact meter-relay as made by Assembly Products is an indicating meter with built-in micro-contacts which can be set to operate at any point of indication on the scale.

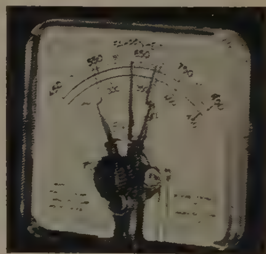
Model 265, plug-in, (non-indicating) hermetically sealed, with shock mounted movement. Suited to marine or aircraft or other mobile installations.



Single contact meter-relay schematic.

Made like a conventional panel meter, it can be substituted for an existing meter in most circuits and will add relay action for over or under limit or automatic control.

A locking coil gives high contact pressure. Spring action in the contacts gives forceful separation. Contacts are released by breaking the circuit to the locking coil, either manually or by an automatic interrupter switch.



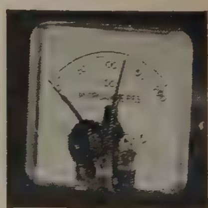
Model 351-C, (3¾ inch), double contact, suppressed zero millivoltmeter, with bimetal compensation for thermocouple reference junction. Dial calibrated 450-850° Fahrenheit (also Centigrade), for Iron-Constantan thermocouple. Used in control of temperature of THERMO DIMPLER made by Zephyr Mfg. Co., Inc., 201 Hindry, Inglewood, Calif.

Model 263, (2½ inch), double contact, (non-indicating) used in Model 653 SILVERCEL BATTERY CHARGER CONTROL manufactured for the Navy by Franklin Transformer Mfg. Co., Minneapolis, Minn.

Send for bulletin 112 listing 11 circuits using meter-relays.

ASSEMBLY PRODUCTS, INC.
P. O. BOX 191
CHAGRIN FALLS 2, OHIO
Phone: CHagrin Falls 7-7374

Model 261-C, (2½ inch), single contact, high limit, 0/200 DC Microamperes as used in Consolidated Engineering Corp., Pasadena, California Model 21-220 Mass Spectrometer.



Industrial Engineering Notes

(Continued from page 128A)

"On the General Theory of Phase Transitions," PB 110584, microfilm, $2.25; photostat, $5. . . . **Naval research has produced a new electronic signal tracer, details of which are available upon request to the "Navy-Technical News," Office of Information, Navy Department, Washington 25, D. C.** The experimental model of a bench-type electronic signal tracer was designed at the Naval Research Laboratory, and it incorporates features proved to be desirable and practical for quick and efficient maintenance of military electronic equipment. One feature of the new laboratory instrument is three probes for trouble location: a tuned r-f probe, an audio probe, and a noisy component probe. . . . **The world's most powerful radio transmitter, the Jim Creek, designed and constructed by the Ra-**

(Continued on page 150A)

Positions Wanted

(Continued from page 144A)

SALES ENGINEER

Attention sales representatives and progressive firms in N.Y.C. and New England area! Will you buy this? BSEE 1949. 2 years electronic test equipment and 2 years microwave engineering; excellent health, 28 years old, married, neat appearance, pleasing personality. Seeking career position in sales. Can you match this? Box 688 W.

MICROWAVE DESIGN ENGINEER

Master's Degree, Physics major, with solid background in design and test of components. Interested in responsible position with N.E. firm. Capable of administrative or sales duties also. Box 689 W.

JR. ELECTRONIC ENGINEER

Age 30. USN—ETMI/c. BEE (eves) due June 1954 from New York University. Experience: 4 years TV repair; presently doing electronic research (2 yrs) for USN. Interested in design and/or development in New York area with a future. Box 690 W.

ENGINEER

BSEE 1951. Single, Age 32. Two years design and development of terminal equipment for radio teletype. Four years broadcast station engineer. Three years Army Air Force Radar Maintenance Engineering. Interested in responsible position in Systems Engineering. Prefers to locate in East or South. Box 692 W.

PATENT ENGINEER

BEE, MSEE, 4 years tube and transistor circuit research, design, development experience; attending (evening) law school, 50% completed. Desires electronics patent work. Location: permitting convenient continuation of law study. Box 694 W.

(Continued on page 150A)

Industrial Engineering Notes

(Continued from page 148A)

dio Corporation of America under contract to the Navy, officially began operation recently with the transmission of a message dictated by Admiral Robert B. Carney and hand-keyed by Brig. Gen. David Sarnoff, RCA Board Chairman. The giant $14-million transmitter located in the Jim Creek Valley of the Cascade Mountains 55 miles northeast of Seattle, Wash., will directly serve Navy fleet and shore stations in all parts of the world with instantaneous and reliable broadcasts. It has a power of 1,200 kw.

Mobilization

The Federal Civil Defense Administration recently advised RETMA that it was discontinuing further work on a special emergency radio receiver to be used during air attacks. FCDA has been in contact with RETMA and the radio industry since early last year

(Continued on page 151A)

Positions Wanted

(Continued from page 148A)

ELECTRONICS SCIENTIST

BSEE 1926, Stanford University. Broad background in electronics and radio communications, including radio noise, propagation, equipment and instrumentation development. Desire to continue past research in LF and VLF propagation, including storm tracking; or electromagnetic aspects of nuclear development. Prefer west coast or western U.S. Box 695 W.

ELECTRONIC ENGINEER

BSEE Communications Option 1949. Age 28, married. 4 years experience in instrumentation sonar and pulse circuit development. Desires responsible position in design and development with opportunity for graduate study. Location, East of Chicago. Box 697 W.

ELECTRONIC ENGINEER

BEE 1950; Tau Beta Pi; Eta Kappa Nu. Age 29, married. 3½ years design and development experience in pulse circuitry, communication equipment, and radar. Desires permanent position with future. Will locate anywhere. Box 698 W.

ENGINEER—PRACTICAL SALES

Outstanding, Electronic background. Supervisor leading TV field engineering dept.; 3 years sales engineer, 6 years TV instructor, 2 years broadcast engineer, trades editor, 4 years supervisory military communications; F.C.C. licenses—1st radio telephone, 2nd radio telegraphs, ham operator. Single, age 31. Prefer sales. Box 699 W.

(Continued on page 152A)

Industrial Engineering Notes

(Continued from page 150A)

on the proposed low-cost set and a meeting was held with set manufacturers on February 19, 1953. At that time manufacturers were asked, in addition to the proposed small set, to specifically mark their receivers to acquaint the public with the two CONELRAD frequencies. Col. William M. Talbot, Director of the FCDA Warning and Communications Office, wrote James D. Secrest, RETMA Executive Vice President, that the agency believes "it is now the general consensus of the manufacturers that an emergency radio receiver especially manufactured for CONELRAD purposes is not practicable considering all the specifications." He added that the technical requirements imposed by FCDA were such that the re-

(Continued on page 160A)

Positions Open

(Continued from page 138A)

SPECTROSCOPIST—PHYSICIST—ION OPTICS

Whether a native Californian or interested in locating here, you can't go wrong checking Beckman's few career positions now open. Our expansion of a firm commercial business or building some of the world's finest scientific instruments can assure you of a secure future. If the positions above fit your interest and abilities, communicate with our Technical Employment Manager, Beckman Instruments, Inc., 1001 El Centro, So. Pasadena 6, Calif.

ELECTRONIC ENGINEERS

1. Chief Test Engineer for a project engaged in the manufacture of a complex electronic product. 2. An Instrumentation Engineer who will be engaged in problems involving measurement in the general field of engineering. Both positions require electronic engineers, or the equivalent, who have at least four years of progressive experience and are actively engaged in the field of electronics. The salaries are approximately $6,000 per year. It is requested that all interested applicants write to the Naval Inspector of Ordnance, Rochester, N.Y. for additional information or to make application.

Positions Wanted

(Continued from page 150A)

ENGINEER

BEE, age 29, looking for a career position preferably in sales or administrative engineering. Experience includes research and development, test and field engineering. Desire metropolitan New York location. Box 700 W.

ENGINEER

BEE Manhattan College 1952. 1 year experience instructor (lab. & lecture). Electronic and Radio Manhattan College. Age 26, single. Desirous of obtaining employment in industry research or development. Metropolitan area only. Box 701 W.

TRANSLATOR

BSEE Univ. of Calif. 1950, age 25, excellent knowledge of Russian; 2 years teaching experience signal corps; 7 mos. radio and electrical engineer, currently graduate student desiring some free lance work translating technical Russian literature. Box 708 W.

ENGINEER

BEE—City College N.Y. 1951. Age 25, single. 1 year on microwave equipment and component testing. 2 years active duty in Signal Corps on design, evaluation, field instruction of Army radars. Desires challenging R&D position anywhere. Available January 1954. Box 709 W.

ENGINEER

BSEE 1951. Age 26, one child. 2½ years experience in Airborne navigation systems. Desires foreign assignment with suitable living conditions for family. Box 710 W.

ENGINEER—EXECUTIVE

BEE, MEE, BBA; 15 years comprehensive experience planning, development, application of electronic automatic control systems involving radar, computers, data handling, displays; creative and administrative ability; seeks non-defense management opportunity. Box 711 W.

(Continued on page 156A)

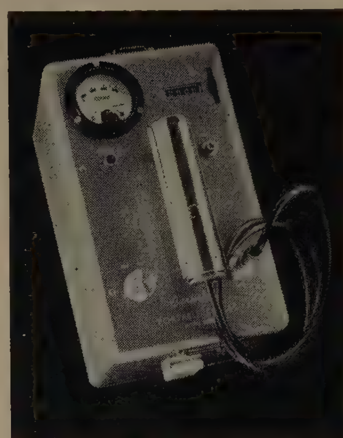
News—News Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 74A)

Portable Scaler

A battery operated portable scaler is now available from **Berkeley, Div. of Beckman Instruments Inc.,** 2200 Wright Ave., Richmond, Calif. It provides a field instrument for accurate measurement of very low beta or gamma radiation levels where the source-to-background ratio is small. With the new Model 2080, it is possible to obtain high accuracy in field measurements where conventional rate meter survey instruments are entirely useless because their statistical accuracy is limited.



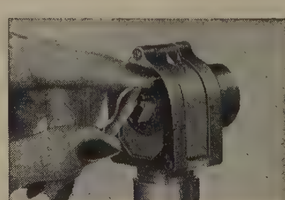
The instrument contains an electronic scale-of-eight and a four-digit resettable register. The electronic scaling binaries use subminiature tubes and are designed for low battery drain and maximum reliability. A meter is used for interpolation of the binary count.

The high voltage supply is of the vibrator type and is regulated at 900 volts by a corona discharge tube. A selection of Geiger tubes and probes is available for use with the instrument.

Maximum counting rate is 100 counts per second and battery life is 60 hours in intermittent use.

Sealed Power Connector

A new series of sealed power connectors are now available from **Cannon Electric Co.,** P.O. Box 75, Lincoln Heights Station, Los Angeles 31, Calif. They have been made to Signal Corps Specifications for power units of audio equipment, and fully described in the 2E-1 Advance Bulletin.



Signal Corps identification of these connectors range from U-112/U to U-117/U. All plugs are the 90° angle type. The wing

(Continued on page 156A)

ULTRASONIC SPECTRUM ANALYSIS

USES

- Ultrasonic Vibration Measurements
- Harmonic Analysis
- Cross Modulation Studies
- Noise Investigations
- Determining Transmission Characteristics of Lines and Filters
- Monitoring Communications Carrier Systems
- Checking Interference, Spurious Modulation, Parasitics, Effects of load changes, shock, humidity, component variations, etc. upon frequency stability
- Telemetering

SPECIFICATIONS

Frequency Range: 2KC—300KC, stabilized linear scale
Scanning Width: Continuously variable from 200KC to zero
Four Input Voltage Ranges: 0.05V. to 50V. Full scale readings from 1 millivolt to 50 volts
Amplitude Scale: Linear and two decade log
Amplitude Accuracy: Within 1 db. Residual harmonics suppressed by at least 50 db.
Resolution: Continuously variable. 2KC at maximum scanning width, 500 c.p.s. for scanning width below 8KC.

EASY FAST

MODEL **SB-7**

PANORAMIC ULTRASONIC ANALYZER

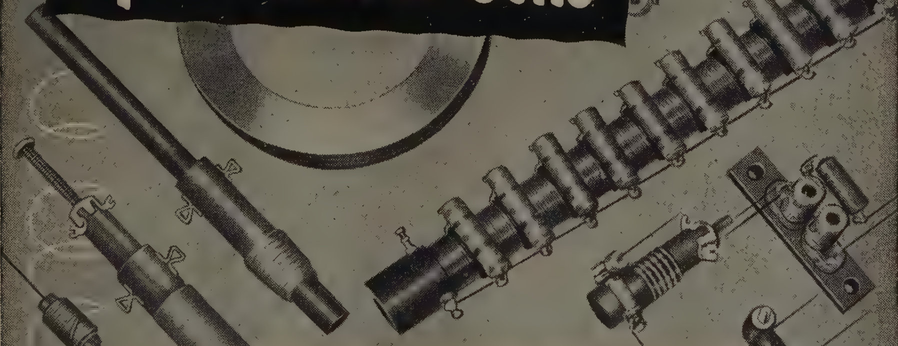
An invaluable new direct reading instrument for simplifying ultrasonic investigations, the SB-7 provides continuous high speed panoramic displays of the frequency, amplitude and characteristics of signals between 2KC and 300KC. The SB-7 allows simultaneous observations of many signals within a band up to 200KC wide. Special control features enable selection and highly detailed examination of narrower bands which may contain signals separated by less than 500 c.p.s. SB-7 is unique in that it provides rapid indications of random changes in energy distribution.

WRITE NOW for complete information, Price, Delivery

PANORAMIC RADIO PRODUCTS, INC.

12 South Second Ave., Mount Vernon, N.Y.
MOunt Vernon 4-3970

Specification Coils



—for every requirement—radio, FM, TV and Government Applications!

Including Universal, Bank Wound, Universal Progressive and Solenoid. All are precision-built to highest engineering standards and conform exactly to specifications. For uniform high quality, prompt delivery and economical unit costs, specify coils by Fugle-Miller. Radio, TV and JAN specifications are a specialty. Phone, wire or write for quotations.

ADDRESS INQUIRIES TO DEPT. P-1

FUGLE-MILLER LABORATORIES
MAIN STREET, METUCHEN, NEW JERSEY
Telephone: Metuchen 6-2245

READY for COLOR TV

with • NEW and IMPROVED BIDECAL PICTURE TUBE SOCKETS
• HIGH VOLTAGE OCTAL and NOVAL SOCKETS WITH CORONA CAPS
• CRYSTAL SOCKETS
Samples upon Request!

METHODE Manufacturing Corp. • 2021 Churchill St. • Chicago 47, Ill.

News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

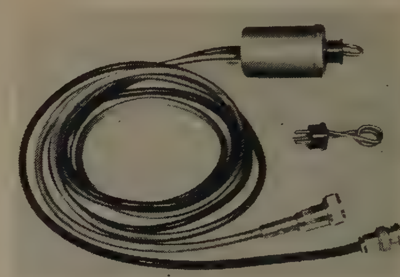
(Continued from page 154A)

blade handle operates a screw for easy engagement and disengagement under conditions in which operator's hand would be gloved. Receptacles are round, with a lock ring for panel mounting. Contact arrangements are 4-No. 16, 12-No. 16 and 29-No. 16 contacts having 2500 v ac rms flashover values.

The neoprene rubber cable gland assures a waterproof fit. Contact engagement is extra long; socket contacts are of the "closed entry" type. Finish is cadmium plate and olive drab chromate treatment.

For further information, write for Bulletin No. 2E-1.

Resonance Indicator



A new Resonance Indicator, Model 60, manufactured by **Dynamic Electronics-**

(Continued on page 158A)

Positions Wanted

(Continued from page 152A)

ELECTRONIC ENGINEER

BEE June 1951. Age 26, married. 2 years Navy ETM2/c. 2½ years field engineering with leading business machine manufacturer. Attending evening graduate school. Desires challenging position in design or electronic research and development, Metropolitan area. Will accept trainee position in this field. Available immediately. Resume on request. Box 712 W.

ELECTRONICS RESEARCH

BEE 1946, MEE 1950 electronics. Age 28, married, one child. Three years experience radio navigation systems research, creative design, construction, analysis, laboratory and field evaluation. Officer Naval Reserve. Presently employed government research activity. Desire similar position with advancement opportunity industry or university research program. Box 713 W.

ENGINEER

Competent engineering group, experienced in radar, instrumentation and data reduction systems; wishes to contact persons interested in backing an electronics engineering company in Southern California. Box 714 W.

ENGINEER

SB and SM EE, Mass. Inst. of Tech, 1950, 1951. Member of Eta Kappa Nu, Tau Beta Pi, Sigma Xi. Two years development experience in analogue computers, servomechanisms and relay switching circuits. Age 27. Desires position with future. Anywhere in U.S.A. Will not consider classified work. Box 715 W.

(Continued on page 158A)

News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 156A)

New York, Inc., 73-39 Woodhaven Blvd., Box 188, Forest Hills, N. Y., is a unit which measures the parallel-resonant frequency of circuits from below 10 mc to above 100 mc. Because of the small probe size passive, unenergized circuits hitherto inaccessible, may be checked and isolation of the desired circuit can be assured. This instrument will permit a wide range of applications in development, production and trouble-shooting work. It can be used to measure self-resonance of rf coils, to search for parasitic resonances, to pretune rf and IF circuits, to provide quick checks for shorted turns and Q of coils, and so forth. All of these measurements can be made without applying power to the circuit under test, and without disturbing the natural environment of the circuit.

This Resonance Indicator uses as accessories, signal generators and a microammeter. No additional accessories are required. Price is $29.75.

(Continued on page 161A)

Positions Wanted

(Continued from page 156A)

ENGINEER

BEE Rensselaer Polytechnic Inst. 1942. Graduate work in Physics, seeks management opportunity with progressive New England firm. Broad and practical experience in project direction including present position as Chief Engineer. Specialist in electromagnetic engineering and microwave circuits. Box 716 W.

ELECTRONIC ENGINEER

BEE 1946, graduate work in EE. Married, age 31. Experience in commercial TV; 3 years in application and test of electronic components used in airborne gear to government specifications. Desire position on government contract work in N.Y. Metropolitan area. Box 717 W.

PHYSICIST—ELECTRONIC SCIENTIST

Single—Age 25—Veteran. BS in Engineering Physics 1951 N.Y.U. Desires position in either Research and Development or Overseas Field Engineering. Experienced in Commercial and Military Microwave Communications Systems, also has experience in Transistor Theory and Applications. Box 718 W.

ENGINEER—PHYSICIST

Physics Graduate, 2 years graduate work, strong mathematics. Two years experience on digital computer design and development. Two years general experience involving information theory, instrumentation, telemetering, technical writing. Eight years Navy Radar experience including time as instructor. Desire position with small organization. New England location outside of metropolitan areas preferred. Box 719 W.

ENGINEER

BE mechanical and electrical major Feb. 1950. Age 32, married. 3½ years Navy instrument electrician. Experience product engr., ASME & ASTM inspection. Desires quality control, plant maintenance or related sales position, Indiana, Michigan or Ohio preferred. Box 720 W.

(Continued on page 170A)

color TV shadow masks

We are now delivering shadow masks, the precision heart of the color television tube, etched to specifications. Mass production methods, perfected during more than 40 years of precise metal etching experience, enable us to meet today's exacting demands for quality and delivery.

etched and electro formed precision parts

With the technical experience and production know-how gained in producing fine metal etching and in electro-forming, we are now manufacturing many components for the electronic industry. Some specifications call for fine mesh up to 1,000,000 holes per square inch. Send us your drawings for a prompt quotation.

BM **BUCKBEE MEARS COMPANY**

Lindeke Building
SAINT PAUL 1, MINNESOTA

STOP RF LEAKAGE ON THE DRAWING BOARD

and color & local osc

. . . WHEN YOU DESIGN METEX ELECTRONIC WEATHERSTRIPPING INTO YOUR EQUIPMENT YOU GET ITS POSITIVE SHIELDING EFFECTIVENESS —AT MAXIMUM OVERALL ECONOMY

Plan *now* to take full advantage of *Metex Electronic Weatherstripping's* unusual effectiveness in shielding all types of electronic equipment. Because it is made of *knitted* wire mesh, *Metex Electronic Weatherstripping* is both conductive *and* resilient. It assures positive metal-to-metal contact between all mating surfaces. And being resilient it accommodates itself positively to surface inequalities.

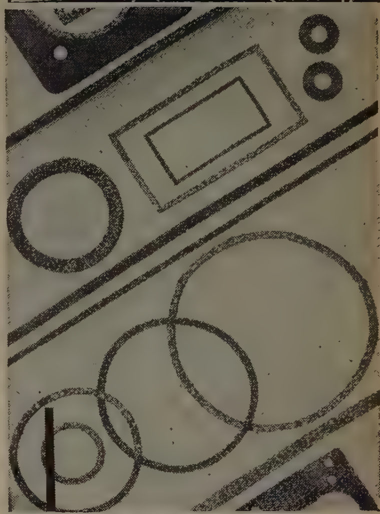
In reality, *Metex Electronic Weatherstripping* can do more for you than just shield RF leakage. It can cut the cost of machining mating surfaces to close tolerances. It can eliminate the need for extra fasteners and many other costly means of making joints RF tight.

To get the best results and lowest production costs, design with *Metex Electronic Weatherstripping*, available in 3 basic forms:

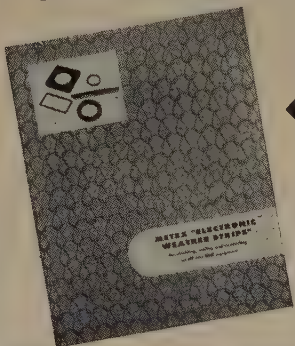
1 Continuous lengths in various cross sectional shapes with or without fin for attachment.

2 Die-formed shielding gaskets, and

3 Sealing gaskets where the knitted wire gasket is combined with a sealing medium.



METEX ELECTRONIC WEATHERSTRIPPING
For shielding on all types of electronic and electrical equipment



For detailed information on METEX ELECTRONIC PRODUCTS, write for FREE copy of "Metex Electronic Weatherstrips" or outline your SPECIFIC shielding problem — it will receive our immediate attention.

Each of these is made in various sizes and shapes which are readily adaptable to practically any equipment. The resiliency can be varied where necessary to meet specific requirements.

Applications in which *Metex Electronic Weatherstripping* has already proved its effectiveness include pulse modulator shields, wave-guide choke-flange gaskets, local oscillators on TV sets, dielectric heaters, etc.

METAL TEXTILE CORPORATION

KNITTERS OF WIRE MESH FOR MORE THAN A QUARTER CENTURY

Roselle, New Jersey

Industrial Engineering Notes

(Continued from page 151A)

ceivers would have to be generally equal to those already on the market. The FCDA officials thanked the industry and RETMA for their co-operation and asked manufacturers to continue to mark CONELRAD frequencies on their set dials and to attach instructions to their receivers. . . . **A reconstitution of the advisory groups for electronics and other major fields within the office of the Assistant Secretary of Defense for Research and Development was predicted recently by Donald A. Quarles.** The Assistant Defense Secretary said in a speech before the Institute of Industrial Research in Detroit that "to benefit from the experience of civilian scientists in the planning and review of our activity, it is planned to establish technical advisory panels in the various scientific and technical fields." He went on to say that "these panels are to consist entirely of persons selected for their professional competence" in the various fields, but did not specify whether the advisory groups would include military personnel in the various fields. . . . **The Bureau of Labor Statistics, Department of Labor, in co-operation with the Department of Defense, recently released a comprehensive and detailed report on the nation's industrial research, "Scientific Research and Develop-**

(Continued on page 162A)

New Plant for Air Marine Motors

Air Marine Motors, Inc., manufacturers of subfractional electric horsepower motors, have moved into their new factory located at 369 Bayview Ave., Amityville, L. I. N. Y.

News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 158A)

UHF Sweep Generator

The New London Instrument Co., P.O. Box 189, New London, Conn., announces the Model 130 UHF Sweep Generator. Featuring single-range tuning and a 0 -to -30 -mc sweep width, Model 130 is designed for laboratory, production test, and service department use.

Other features are: at least one volt

(Continued on page 165A)

Industrial Engineering Notes

(Continued from page 160A)

ment in American Industry." The material expands previous data released by the Research and Development Board. Nearly 2,000 companies, with about 6.5 million employees, and sales totaling nearly \$100 billion in 1951, were studied. Of the number of companies reporting by mail questionnaire that they were qualified to do research and development, the survey for the electronics industry is based on figures reported by electronics firms. It was pointed out that the cost of all research by the reporting companies in 1951 was \$1,804,529,000 and for the electronic equipment industry the cost was placed at \$531,668,000. The survey reported that of the 277 electronics companies reporting, 58.5 per cent of their research cost was government-financed. The average cost per research engineer or scien-

(Continued on page 164A)

Industrial Engineering Notes

(Continued from page 162A)

tist was placed at $27,500 by all the reporting electronics companies. Other topics discussed in the report include the rate of turnover of professional research staffs and the past and potential effects of military calls of such employes; research engineers and scientists as a per cent of total company employment; research costs as a per cent of sales; both employment and costs of government prime contracts and subcontracts for defense research. In all sections of the report, separate figures are given for major manufacturing and nonmanufacturing industries and for companies of different sizes. Copies of the report, Bulletin No. 1148, "Scientific Research and Development in American Industry," of the Bureau of Labor Statistics, may be purchased from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., for 50 cents a copy. . . . **The Department of Defense released a directive recently outlining the responsibilities being assigned to Assistant Secretary of Defense for Research and Development, Donald A. Quarles.** Primarily, he and his staff will develop policies and establish procedures for effecting a sound and integrated research and development program in the Department of Defense. The directive goes one step further in the integration picture, however, and gives Mr. Quarles authority "for assigning specific responsibilities to the various military departments for research and development programs in cases where it appears that unnecessary duplication will be eliminated, efficiency promoted and economy achieved by such action."

Television

The Big Spring Broadcasting Co. recently joined Zenith Radio Corp. and seven other petitioners

(Continued on page 166A)

News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I R.E. affiliation.

(Continued from page 161A)

output into 75 ohms; continuousy variable attenuator; a blanked signal on the return sweep, thus providing a reference base line; no beating; no multiplication; simplicity of operation.

The Model 130 sells for $265.00 f.o.b. New London, Conn. A low-cost balun is available for conversion to 300 ohm load.

Wire Markers

Northshore Name Plate Co., Glenwood Landing, L. I., N. Y., is now ready to deliver their new Speedy Marx Hi-Temp Wire Markers.

Capable of resisting heat up to 400°F these new Hi-Temp markers offer a simple identification system for a large assortment of uses. Now Selenium rectifiers, electric motors, and transformers of any application where temporary rise is considerable over ambient, can be marked with Speedy Hi-Temps. The special pressure sensitive tape made to a rigid specification, insures permanent identification on a wide variety of surfaces. There is no effect from cold, humidity, or vibration. These markers are made on standard Speedy Marx Cards or can be made to your size and specifications. Catalog available on request.

(Continued on page 167A)

Industrial Engineering Notes

(*Continued from page 164A*)

in requesting that the Federal Communications Commission immediately institute rule making proceedings looking toward adopting rules, regulations, and standards for a subscription television service. The petitioner, an applicant for Channel 4 in Big Spring, Tex., stated, in favor of subscription TV as a broadcast service, that "subscription television service would be a valuable adjunct to television stations' program service by enabling stations to make available to their audiences programs that otherwise could not be broadcast by the stations because of restrictions placed on the program by the party in control of the program material, and will enable television stations in medium-sized markets to provide a better program service and operate longer hours than would otherwise be economically feasible." . . . **A new Ultra High Frequency TV Association has been formed by a group of station operators which elected Lou Poller, KCAN-TV, Milwaukee, as President.** Through its Washington counsel, William Roberts, the association has written to Federal Trade Commission Attorney Paul Butz urging that in its consideration of the proposed Trade Practice Rules for the Radio and Television Industry, the definition of a TV receiver be written "so that that term can only be used to describe a receiving set which is constructed for and capable of receiving . . . all channels allocated by the FCC." If a receiving set is not capable of such reception, additional disclosure should be required in order to protect the consumer from deceptive advertising. A letter also was directed to the FCC by the group, charging that the Commission has made some drastic changes in its processing procedures since the end of the freeze which the UHF opera-

(*Continued on page 168A*)

News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 165A)

VHF Cascode Amplifier

Sylvania Electric Products Inc., Sales Dept., 1740 Broadway, New York, N. Y., announces a new tube, suited to grounded grid balanced amplifier service.

The new tube, Type 6BQ7A is for frequencies up to 300 mc. It is another of the vhf cascode amplifier tube series with higher gain than its prototype, the 6BQ7. The 6BQ7A has a gm of 6400 μmhos and an amplification factor of 38 with 150 volts applied to the plate. It can be used as a replacement for the 6BQ7 with slight realignment of the tuned circuits.

Further information is available by writing Sylvania.

(Continued on page 171A)

Industrial Engineering Notes

(Continued from page 166A)

tors had not been led to expect. He also pointed out what were termed "serious disabilities affecting UHF," including delays in the availability of high-powered transmitters, "lack of adequate converters," and all-channel sets, and problems in obtaining network affiliations for UHF stations.

RETMA Activities

A fifth government-industry conference designed to promote continued improvement in the quality of electronic components and to disseminate data on new technical progress has been scheduled in Washington on May 4–6, 1954, according to M. Barry Carlton of the Department of Defense, Chairman of "The 1954 Electronic Components Symposium." The three-day technical meeting will be held in the auditorium of the U. S. Department of the Interior. The 1954 symposium is sponsored by RETMA, the American Institute of Electrical Engineers, the Institute of Radio Engineers and the West Coast Electronics Manufacturers Association with the active participation of the U. S. Department of Defense and the National Bureau of Standards. The Technical Program Committee is under the chairmanship of S. W. Rogers, of the Signal Corps. Mr. Rogers and his committee of leading experts in the electronics field plan to develop a theme during the session depicting the technical progress in materials and component development, fabrication, and use with emphasis on the part played by components in electronic reliability. Speakers from government and industry will be featured during the symposium. RETMA's participation in the symposium is directed by L. M. Clement, of Crosley Radio and Television Division, and R. R. Batcher, Chief Engineer of the Association.

(Continued on page 170A)

Industrial Engineering Notes

(Continued from page 168A)

FCC Actions

FCC Commissioner E. M. Webster recently released a letter setting forth his views regarding the allocation of frequencies in the 88–108 mc FM band. The letter was directed to Ben Strouse, Chairman of the FM Committee of the National Association of Radio and Television Broadcasters, in response to a previous communication. The Commissioner emphasized that the views expressed by him were his own and did not necessarily reflect those of the FCC. He said, however, "The Congress had charged the Commission with the duty of determining the most efficient use of the spectrum allocated for non-government purposes . . ." and "surely the Commission has given no assurance to any service that it

(Continued on page 175A)

Positions Wanted

(Continued from page 158A)

DIRECTOR OF ENGINEERING

MS in EE 1938. Fifteen years responsible engineering in Government and industry. Technical direction of 400 professional men in digital computer and electromechanics. Sales and contract experience. Capable to start, build and operate engineering group. Box 721 W.

ENGINEER

BEE, over twelve years varied experience, including radar, circuits, aircraft instruments, optics, special electronic devices, supervision and report writing. Several patents. Desires creative responsible position. Box 722 W.

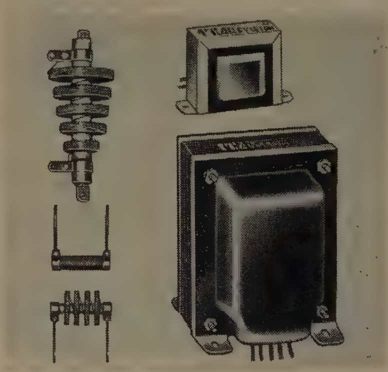
News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 167A)

Transformers and Coils To Specifications

Transvision, Inc., has established a **Transformer and Coil Mfg. Div.** at New Rochelle, N. Y. This department is devoted to designing, engineering and manufacturing high frequency air core coils, multi-layer selenoid coils, peaking coils, synchro winding coils, television rf and IF coils to specifications, as well as transformers for audio, power, high voltage, pulse application, and synchro use.

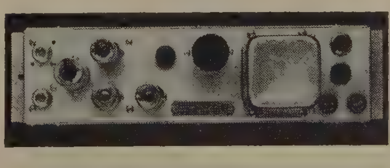


Particularly helpful is the "short run" feature of this Transvision manufacturing service. Where only a few samples are required for experimental work, the requisition is accommodated. There are newly enlarged facilities for full-scale fabrication and assembly after approval of initial units.

This division also engages in the manufacture and assembly of electronic components, sub-assemblies, and instruments for governmental or civilian use. Sketches and blueprints are invited for estimating. For a 4-page brochure and further details, write to the firm.

Automatic Level Control

Spencer-Kennedy Laboratories, Inc., 186 Massachusetts Ave., Cambridge 39, Mass., have a new Model 442 Automatic Level Control designed to automatically maintain proper signal strengths in a television distribution system. Cross modulation can be eliminated by the Model 442 because the proper signal levels are automatically maintained.



This control will compensate for changes in cable transmission characteristics without further attention. Deteriora-

(Continued on page 173A)

Industrial Engineering Notes

(Continued from page 170A)

will permit the frequencies loaned thereto to remain inefficiently used indefinitely." He said that "the length of time given to a service to put its frequencies to efficient use must presently be determined on a case-to-case basis . . . " but "I can only say that, in my opinion, it would be detrimental to the public interest to permit a valuable part of the public domain to lie fallow indefinitely in the face of the rapidly growing demand for radio frequencies in all phases of our social and economic life." He pointed out that, of course, any petition which might be filed requesting a reassignment of frequencies in the FM band would have to stand on its own merits. . . . The FCC granted construction permits recently for a new common carrier microwave relay sys-

(Continued on page 177A)

News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 173A)

24 Hour Recorder

Soundscriber Corp., 146 Munson St., New Haven 4, Conn., manufacturer of dictation equipment, has a recorder which is capable of delivering 24 and 48 hours of continuous, unattended magnetic recording on either one or two channels of communication simultaneously, on a single reel of tape.

More than 500 of the recorder reproducers have been in use during the past year at Naval air stations, where they are being used to record ground-to-air, air-to-ground communications. Production of the equipment for commercial use now has been started.

The equipment is able to record the exact time messages are received, by means of a printed time-scale on the three-inch-wide tape. The tape also measures elapsed time between recordings and allows fast place-finding without an audible search.

A buzzer sounds if a power failure occurs, or when the machine nears the end of the tape, or if the tape breaks. The instrument plays back instantly.

The recorder-reproducer can be used efficiently wherever there is need for an unmanned, uninterrrupted "listening device" that can retain long communications and reproduce them, automatically timed to the minute. The tape employed can be erased by a bulk demagnetizer in 20 seconds.

Dielectric Capacitor

Film Capacitors Inc., 337 E. 139 St., New York, N. Y., is now producing Teflon dielectric capacitors for operation at temperatures up to 200°C. These capacitors are characterized by high I.R. and low power factor.

For temperatures up to 150°C, units are furnished in glass tubes with hermetically sealed metal caps, or in standard JAN cans.

For temperatures up to 200°C, units are furnished in glass tubes with resin seals or in standard cans using special alumina terminals and high melting point solders.

Ratings range from 0.005 μf to 1 μf at 500 volts dc.

(Continued on page 178A)

Industrial Engineering Notes

(Continued from page 175A)

tem to link Laramie and Casper, Wyo., which will be available for TV and other common carrier microwave transmission services. The CP went to the Mountain States Telephone and Telegraph Co., and its proposed initial customer is a community TV system which will pick programs of Denver stations off the air with a receiving antenna on Crow Creek Hill near Laramie, and have these common carrier microwave facilities transmit them to Casper, where they will be delivered to the community TV system's wire lines for distribution by the latter to its members. . . . The Federal Communications Commission recently finalized a Notice of Proposed Rule Making issued in August by amending Part 4 of the Rules and Regulations Governing Auxiliary

(Continued on page 178A)

Industrial Engineering Notes

(Continued from page 177A)

Broadcast Services so as to make provision for FM inter-city relay stations in the band 940–952 mc. The frequencies will be used for network operations where suitable common carrier facilities are not available, provided no harmful interference is caused to broadcast studio transmitter link stations operating in that band. This Order becomes effective 30 days after its publication in the Federal Register.

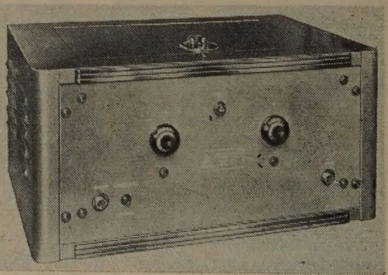
News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 176A)

Differential Analyzer

Radiation Counter Laboratories, Inc., 5122 W. Grove St., Skokie Ill., has announced the availability of the Oak Ridge Single-Channel Differential Analyzer, RCL Mark 15 Model 2204, (ORNL-Q-1192; Model 5). The circuit of the Differential Analyzer consists of an expander amplifier using Type 404A pentodes. The cathode follower output of the feedback amplifier supplies a portion of the input signal, amplified by a factor of ten to the upper level discriminator, and the lower level discriminator. The output of the discriminator circuits (also 404A pentodes) feed into the memory and anti-coincidence circuits.



An IN38A crystal diode is used to prevent the plate voltage of the first amplifier 404A from falling more than five volts below its quiescent value. This limited potential swing will allow this plate to recover rapidly after a large signal. Also, an abrupt and fast rise of the output pulse is assured through the use of an "amplified-diode" breakaway circuit.

The Single Channel Analyzer may be used in conjunction with the ORNL A1C Linear Amplifier and ORNL A1C Linear Preamplifier, which are also manufactured by Radiation Counter Laboratories, Inc.

For further technical information and price data, write Department PF-9.

(Continued on page 180A)

COMMUNICATIONS EQUIPMENT CO.

RADAR SETS

SO-1 10 cm. with a range of 4, 20, and 80 miles. PPI presentation on a 5 inch screen. 360 deg. rotation of antenna with a pattern 8 deg. in horiz. and 18 deg. in vert. plane. Operates from 115 vdc. Set consists of following: antenna, m/g—modulator, xmtr—rcvr, PPI unit, accessory control, and rectifier power unit.

MK 10 GUN RADAR. Extremely accurate, rugged and compact. Designed for ship board use to direct naval gun turrets. Antenna utilizes conical scanning for accurate pointing. Max. range is 20,000 yards with an error of pm 15 yds pm .1% of range. Pointing accuracy is pm .25 deg. Pulse dur. 0.5 usec. at prr of 3600 cps. Pk. power output is 25 Kw. Primary power consumption is 1300 watts. Operates from 115V. 60 CPS Source. BRAND NEW, COMPLETE WITH SPARES AND INSTRUCTION MANUAL .... POR*

SQ Portable radar with type PPI, "A", or "B" Scope. Frequency is Approx. 3000 Mcs. 3 ranges: 3, 15, and 45 miles. Operates from 115v, 60 cycles $850

SE 10 cm radar for use on small surface craft for Sea-Search use. Max. range 80,000 yards, with an accuracy of 100 yards ± 1% of range. Bearing accuracy 2 degrees. Operates from 115 VDC. Complete Equipment, Brand new, in original matched sets @ $850.C0

SN Portable, lightweight, 10 cm set with ranges of 4 and 20 Mi. Presentation is on 5" "A" Scope. Operates from 115V, 50-60 Cy. Ideal for labs, Classrooms, and small boats $850.00

IFF SETS RC 148 RC 145 RC 184 RC 188 Navy BM

PRICE ON REQUEST

HI-POWER COMPONENTS

PLATE TRANS. Primary: 115V, 50-60 CY. Sec. 17, 600V/144 MA. Has "Built-in" Filter choke. Oil immersed $115.00

PLATE TRANS. Pri: 198/220/240V, 60 cy, 1 PH. Sec: 3650V/16.7 KVA, 30KV insulation. Oil-immersed, Less oil gauge $335.00

PLATE TRANS. AMERTRAN #31133. Pri: 110/115/120V/60cy/1 phase. Sec: 3140/1570V. 2.36 KVA $105.00

FIL. TRANS. Pri: 220V/60cy/1 phase. Sec: 5 VCT/10A/30 KV TEST $37.50

PLATE TRANS. RAYTHEON UX 6801. Pri: 115V/60cy/1 PH. Sec: 22,000 V/234 MA/5.35 KVA. LO-CAP "DONUT" Construction $135.00

REACTOR RAYTHRON U-11533: 13.5H @ 1.0 AMP, 13.5 KV TEST ....

REACTOR, MODULATION: 50H/3A/80 OHMS DCR. Response: .03 cy-10 KC. Level: Plus 63 db. 40 KV. Test. Nominal Circuit impedance: 3000 Ohms $350.00

SWING REACTOR: 9-60 HY/.05-400 Ma, 10,000 V. Test Kenyon $14.95

MAGNETRONS

Type	Freq. Range(MC)	Peak Power Out (KW)	Duty Ratio	Price
2J21A	9345-9405	50		$8.75
2J22	3267-3333	265		7.50
2J27	2965-2992	275	.002	19.95
2J31	2820-2860	285	.002	24.50
2J32	2780-2820	285	.002	28.50
2J38*	3249-3263	5		16.50
2J39*	3267-3333	8.7		24.50
2J48	9310-9320	50	.001	24.50
2J49	9000-9160	50	.001	59.50
2J56*	9215-9275	50	.001	132.50
2J61†	3000-3100	35	.002	34.50
2J62†	2914-3010	35	.002	34.50
700B	690-700	40	.002	22.50
700D	710-720	40	.002	39.75
706EY	3038-3069	200	.001	32.50
706CY	2976-3007	200	.001	32.50
725-A	9345-9405	50	.001	Write
730-A	9345-9405	50	.001	24.50
4J38	3550-3600	750	.001	169.45

*—Packaged with magnet.
†—Tunable over Indicated range.

QK 60, 61, 62—$85 ea.

KLYSTRONS

723A .... $12.50 | 2K25/723A/B $27.50
723A/B ...... 19.50 | 417-A (Sperry) 17.50

MICROWAVE COMPONENTS

"S Band," RG48/U Waveguide

POWER SPLITTER for use with type 726 or any 10 CM Shepherd Klystron. Energy is fed from Klystron antenna through dual pick-up system to 2 type "N" connectors..$22.50 EACH

DIRECTIONAL COUPLER. Broad-band type "N" Coupling, 20 db. with std. flanges, Navy #CABV47AAN-2 (as shown) $37.50

LHTR, LIGHTHOUSE ASSEMBLY. Part of RT39 APG 5 & APG 15. Receiver and Trans. Cavities w/assoc Tr. Cavity and Type N CPLG. To Recvr. Uses 2C40, 2C43, 1B27, Tunable APX 2400-2700 MCS. Silver Plated $49.50

BEACON LIGHTHOUSE cavity p/o UPN-2 Beacon 10 cm. Mfg. Bernard Rice, each $47.50

MAGNETRON TO WAVEGUIDE Coupler with 721-A Duplexer Cavity, gold plated $45.00

RT-30 APG-5 10 cm. lighthouse RF head c/o Xmtr.-Recvr-TR, cavity compl. recvr. & 30 MC IF strip using 60K5 (2C40, 2C43, 1B27 lineup) w/Tubes.

721A TR BOX complete with tube and tuning plungers $12.50

McNALLY KLYSTRON CAVITIES for 707B or 2K28 .... $4.00

WAVEGUIDE TO 7/8" RIGID COAX "DOOR-KNOB" ADAPTER CHOKE FLANGE, SILVER PLATED BROAD BAND $32.50

AS14A AP-10 CM Pick up Dipole with "N" Cables $4.50

OAJ ECHO BOX. 10 CM TUNABLE $22.50

HOLMDELL-TO-TYPE "N" Male Adapters, W.E. #D167284 .... $2.75

I.F. AMP. STRIP: 30 MC, 30 d.b. gain, 4 MC Bandwidth, uses 6AC7's—with video detector. A.F.C. less tubes $24.50

POLYROD ANTENNA, AS31/APN-7 in Lucite Ball. Type "N" feed $22.50

ANTENNA, AT49A/APR: Broadband Conical. 300-3300 MC Type "N" Feed $12.50

"E" or "H" PLANE BENDS, 90 deg. less flanges $7.50

X Band—RG 52/U WAVEGUIDE

VSWR Measuring Section. Consisting of 6" straight section, with 2 pick-up, Type "N" Output Jacks. Mounted ½ Wave apart $8.50

1" x ½" waveguide in 5' lengths, UG 39 flanges to UG40 cover .... per length $7.50

Rotating-joints supplied either with or without deck mounting. With UG40 flanges .each, $17.50

Bulkhead Feed-thru Assembly $15.00

Pressure Gauge Section 15 lb. gauge and press nipple $10.00

Pressure Gauge, 15 lbs. $2.50

Directional Coupler, UG-40/U Take off 20db $17.50

TR-ATR Duplexer section for above $8.50

Waveguide Section 12" long choke to cover 45 deg. twist & 2½" radius, 90 deg. bend $4.50

Waveguide Section 3 ft. long silver plated with choke flange $5.75

Rotary joint choke to choke with deck mounting $17.50

90 degree elbows, "E" plane 2½" radius ..$12.50

Microwave Receiver, 3 CM. Sensitivity: 10-13μ Watts. Complete with L.O. and AFC Mixer and Waveguide Input Circuits. 6 I.F. Stages give approximately 120 DV gain at a bandwidth of 1.7 MC. Video Bandwidth: 2 MC. Uses latest type AFC circuit. Complete with all tubes, including 723A/B Local Oscillator $175.00

ADAPTER, waveguide to type "N", UG 81/U, p/o TS 12, TS-13, Etc. $27.50

ADAPTER, UG-163/U round cover to special btl. Flange for TS-45, etc. .... $2.50 ea.

K Band—½" x ¼" W.G. 1.25 CM.

APS-34 Rotating joint $49.50

Right Angle Bend E or H Plane, specify combination of couplings desired $12.00

45° Bend E or H Plane, choke to cover $12.00

Mitered Elbow, cover to cover $4.00

TR-ATR-Section. Choke to cover $4.00

Flexible Section 1" choke to choke $5.00

"S" Curve Choke to cover $4.50

Adapter, round to square cover $5.00

Feedback to Parabola Horn with pressurized window $27.50

90° Twist $10.00

WAVEGUIDE FLANGES

UG 39/U .... $1.10 | UG 51/U $1.65
UG 40/U .... $1.25 | UG 52/U $3.40
UG 40A/U ...... $1.65 | UG 52A/U $3.40

PULSE NETWORKS

15A—1-400-50: 15 KV, "A" CKT. 1 microsec. 400 PPS, 50 ohms imp. $37.50

G.E. #3E (3-84-810) 8-2.24-405) 50P4T ; 3KV "E" CKT Dual Unit; Unit 1, 3 sections, 0.84 Microsec. 810 PPS, 50 ohms imp.; Unit 2, 8 Sections, 2.24 microsec. 405 PPS 50 ohms imp. $6.50

7-5E3-1-200-67P. 7.5 KV "E" Circuit. 1 microsec. 200 PPS, 67 ohms impedance 3 sections $7.50

7-5E4-16-60, 67P. 7.5 KV "E" Circuit, 4 sections 16 microsec. 60 PPS, 67 ohms impedance $15.00

7-5E3-3-200-67P, 7.5 KV, "E" Circuit, 3 microsec. 200 PPS, ohms imp. 3 sections $12.50

#755: 10KV. 2.2usec., 375 PPS. 50 ohms imp. ...$27.50

#754: 10KV. 0.85usec., 750 PPS. 50 ohms imp. ...$27.50

KS8865 CHARGING CHOKE: 115-150 H @ .02A, 32-40H @ .08A, 30,700V Corona Test, 21KV Test $37.50

G.E. 25E5-1-350-50 P2T. "E" SKT, 1 Microsec. Pulse @ 350 PPS. 50 OHMS Impedance $69.50

KS9623 CHARGING CHOKE: 16H @ 75 MA, 380 Ohms DCR, 9000 Vac test $14.95

G.E. 6E3-.5-2000 50 P2T: 6 KV., "E" Circuit 0.5 usec /2000 PPS/50 ohms/2 sections $7.50

PULSE EQUIPMENT

MIT. MOD. 3 HARD TUBE PULSER: Output Pulse Power 144 KW (12 KV at 12 Amp). Duty Ratio: .001 max. Pulse duration: 5, 1.0, 2.0 microsec. Input voltage: 115 v. 400 to 2400 cps. Uses: 1-71B, 4-89-B, 3-'72's, 1-'73. New .... Less Cover—$135

TPS-3 PULSE MODULATOR. Pk. power 50 amp. 24 KW (1200 KW pk): pulse rate 200 PPS. 1.5 microsec. pulse line impedance 50 ohms. Circuit series charging version of DC Resonance type. Uses two 705-A's as rectifiers. 115 v. 400 cycle input. New with all tubes $49.50

PULSE TRANSFORMERS

GE #-2748-A 0.5 usec @ 2000 Pps. Pk. Pwr out is 32 KW impedance 40:100 ohm output. Pri. volts 2.3KV Pk. Sec. volts 11.5 KV Pk. Bifilar rated at 1.3 Amp. Fitted with magnetron well $39.50

GE #K-2449A Primary: 9.33 KV, 50 ohms Imp. Secondary: 28 KV, 450 ohms. Pulse length: 1.0/5 usec @ 635/120 PPS. Pk. Power Out: 1,740 KW Bifilar: 1.5 amps $62.50

K-2745 Primary: 3.1/2.8 KV, 50 ohms Z. Secondary: 14/12.6 KV 1025 ohms Z. Pulse Length: 0.25/1.0 usec @ 600/600 PPS. Pk. Power 200/150 KW. Bifilar: 1.3 Amp. Has "bilt-in" magnetron well $42.50

K-2461A Primary: 3.1/2.6 KV—50 ohms (line). Secondary 14/11.5 KV—1000 ohms Z. Pulse Length: 1 usec @ 600 PPS. Pk. Power Out: 200/130 KW. Bifilar: 1.3 Amp. Fitted with magnetron well $39.75

UTAH X-151T-1: Dual Transformer, 2 Wdgs. per section 1:1 Ratio per sec 13 MH inductance 30 ohms DCR $7.50

UTAH X-150T-1: Two sections, 3 Wdgs. per section. 1:1:1 Ratio, 3 MH, 6 ohms DCR per Wdg. $7.50

68G711: Ratio: 4:1 6.7 Ohms. Pri: 0.23 Ohms sec. $4.50

TR1049: Ratio: 2:1 Pri. 220 MH, 50 Ohms, sec. 0.75H, DCR 100 Ohms $6.75

K-901695-501: Ratio 1:1, Pri. Imp. 40 Ohm, Sec. Imp. 40 Ohms. Passes pulse 0.6 usec with 0.05 usec rise $8.95

Ray UX 7896—Pulse Output Pri. 5v. sec. 41v. ...$7.50

Ray UX 8442—Pulse inversion—40v + 40v $7.50

PHILCO 352-7250, 352-7251, 352-7287

RAYTHEON: UX8693, UX5986 .... $5 ea.

W.E.: D-166310, D-166638, KS 9800, KS9948.

UTAH #9262, with Cracked Beads, but will operate at full rated capacity $5.00

UX 8693 (SCS #2Z9627-54): 3 Wdgs. 32 turns #18 wire. DCR is: .362/.372/.4 ohms. Total voltage 2500 vdc. $5.00

D-166173: Input: 50 ohms Z. Output: 900 ohms 3 Wdgs. Freq. range 10 kc-2mc. P/0 AN/APQ*-13 .... $12.50

K-2450: Pulse-inversion auto-transformer: primary 13 kv, 4 usec. Output: 14 kv @ 100 kw peak $34.50

THERMISTORS

D-164699 Bead Type DCR: 1525-2550 Ohms @ 75 Deg. F. Coefficient: 2% Per Deg. Fahr. Max. Current 25 MA AC/DC $2.50

D-167332 Bead Type, DCR is 1525-2550 Ohms. Rated 25 MA at .825-1.175 VDC $1.50

D-167613 Disk Type DCR: 355 Ohms @ 75 Deg. F.P.M. 2.5%, 1 Watt $1.50

D-166228 Disk Type 7120 Ohms @ 60°F. 4220 Ohms @ 80°F. 2590 Ohms @ 100°F.. 1640 Ohms @ 120°F. $1.50

HELMHOLTZ PHASE-SHIFTER

Stator consists of 4 loops oriented at 90 degrees to each other. Total stator inductance is 40MH. Rotor: 10MH. Total phase shift 0-360 deg. Designed for range unit of SCR-268 .... **3.95 EACH**

MAIL ORDERS PROMPTLY FILLED. ALL PRICES F.O.B. NEW YORK CITY. SEND M.O. OR CHECK. ONLY SHIPPING SENT C.O.D. RATED CONCERNS SEND P.O. ALL MDSE. SUBJECT TO PRIOR SALE, AND PRICES SUBJECT TO CHANGE WITHOUT NOTICE.
PARCELS IN EXCESS OF 20 POUNDS WILL BE SHIPPED VIA CHEAPEST TRUCK OR RAILEX.

131 Liberty St., New York 7, N. Y. Dept I-1 Chas. Rosen Phone: Digby 9-4124

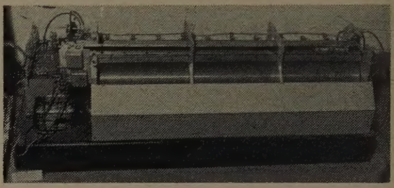
News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 178A)

Magnetic Storage Drums

W. S. MacDonald Co., Inc., 33 University Rd., Cambridge 38, Mass., now produces, as a separate unit, their magnetic storage drums which were originally components of complete equipment. This design and modifications thereof are available in several standard sizes. Where a standard size or capacity of memory will not meet the customer's requirements, other sizes and can be furnished within rather broad limits.

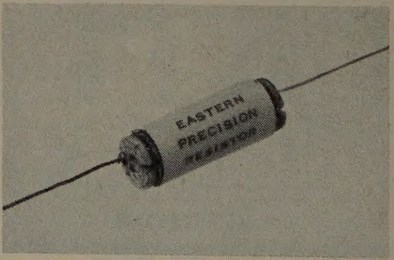


All magnetic storage drums are available with or without fixed or moving heads, slide wires, and associated electronic amplifiers, servosystems, and so forth. All come complete with electric drive motors. The following sizes are representative of those drums which have been produced to date. Type 1 is 4 inch diameter $\times$6 inches long, 1750 rpm, Type 2 is 8$\times$38, 575 rpm, Type 3 is 5$\times$15, 1150 rpm, Type 4 is 6$\times$34, 1150, rpm., Type 5 is 8$\times$1½, 1150 rpm.

Additional data storage capacity may be obtained in larger sizes by combining two drums of the indicated size in one set of end plates. This system has already been used in the Type 4 Drum.

Wire-Wound Resistors

Eastern Precision Resistor Co., Richmond Hill 18, N. Y., is producing a low capacity, precision wire-wound resistor with capacity controlled to 0.5 $\mu\mu f$ with a 1.0 megohm resistor.



These components are suitable for manufacturers and designers of test equipment, electronic computers, meters, and other precision electronic instruments.

Catalog #953 contains data on this and other precision wire-wound components, manufactured by Eastern.